Fifth Annual Wind Energy Symposium Proceedings

Ryerson
Polytechnical
Institute
Toronto, Ontario

December 11th, 1982

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Energy

Honourable
Philip Andrewes
Minister

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5TH ANNUAL WIND ENERGY SYMPOSIUM
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PROCEEDINGS
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DECEMBER 11th,1982

Ryerson Polytechnical Institute
Toronto, Canada

EDITOR:

Nicholas J.M. Teekman, B.Sc.
DynamoGenesis Inc.

These proceedings are a record of the 'state of the art' in 1982 of Canada's research, test, development and planning methodologies and HAWT/VAWT industrial WECS technology. It is published as a public service for the information of the public.

5TH ANNUAL WIND ENERGY SYMPOSIUM

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TABLE OF CONTENTS

PAGE

OPENING REMARKS 2

THE WIND ENERGY RESEARCH AND DEVELOPMENT PROGRAM IN CANADA
M.S. Chappell, National Research Council 3

ONTARIO MINISTRY OF ENERGY - WIND POWER PROGRAM
B. Stewart, Ontario Ministry of Energy 23

THE ROLE OF THE CSA IN DEVELOPING STANDARDS:
STATUS REPORT ON WECS STANDARDS
R. Patterson, Canadian Standards Association 29

COMMERCIALIZATION OF THE 500 KW DARRIEUS VERTICAL AXIS WIND TURBINE
L. Schienbein, DAF Indal Ltd. 43

WIND ENERGY ANALYSIS AT SELECTED SITES IN ONTARIO
B. Morris, Atmospheric Environment Service 49

PROMOD III: EVALUATION OF THE WORTH OF GRID CONNECTED WECS
K. Slater, Slater Energy Consultants Inc. 67

BALANCED STRESS VERTICAL AXIS WIND TURBINE
T.A. Watson 96

THE KORTRIGHT CENTRE'S CONSERVATION AND RENEWABLE ENERGY PROGRAM
P. Leitch, Kortright Conservation Centre 101

WIND ENERGY OVERVIEW: DEVELOPMENT OF SMALL AND LARGE SCALE TURBINES FOR ELECTRIC POWER GENERATION
D. Hoffman, Renewable Energy News 118

THE HELICAL WIND ENGINE: THE STORY UNFOLDS
N. Teekman, Renewable Dynamics Inc. 125

OPENING REMARKS

On behalf of the DynamoGenesis Corporation I would like to welcome you to the 5th Annual Wind Energy Symposium here at Ryerson. Co-sponsored in cooperation with the Ryerson Energy Centre who has sent us Dr. Ken Burkhardt who will welcome you on behalf of Ryerson to the symposium.

The symposium has been going for five years now. It started at Sheridan College in Brampton for the first two years. The first one was organized by Vic Wagner and Dan Shatil. I have been involved on behalf of the DynamoGenesis Corporation since then. The third symposium was at the Highlands Energy Centre in Orangeville and last year's was here at Ryerson.

The first symposium was interesting in that it contained a lot of position papers but not much work actually being done in the field. Speakers were from Energy, Mines and Resources Canada, the Ontario Ministry of Energy, Ontario Hydro and others looking at projections and theoretical considerations in wind, e.g. how much energy was going to be available but not much in terms of actual work. This has changed over the last four symposia in which we covered everything from low speed aerodynamics, battery storage to site selection, all sorts of things.

I'd like to draw your attention to the proceedings which are available for the second and third wind energy symposia. The second one focuses on technical considerations for design (i.e. low speed aerodynamics) and the third wind energy symposium covers more of the nature of wind itself, especially siting windmills. The proceedings from last year's event, the Fourth Wind Energy Symposium is being published under contract with the Ontario Ministry of Energy.

Now, I would like to introduce Ken Burkhardt for a few words of welcome.

I would like to welcome you to Ryerson. Our wind energy program is dormant at the moment. You may know Dave Platnick who passed away in September this year. So there is no activity at the moment in wind energy. However, we do support such efforts. We believe in flexible, stable, secure energy systems. As Charles Darwin says, "there is survival potential in diversity", and for that reason I think it is very valuable that wind energy is being looked at as one of the components of a diverse energy system and I think that is a good effort. Our own efforts presently concentrate on solar cooking as far as "hands-on" research goes. It may seem a small thing but actually I call it the dormant giant of appropriate technology because there are 2-3 billion people out there who desperately need some fuel to cook. The sun offers a basic resource of 1 kW/sq. m, that will meet that need now. I would like to congratulate you Nicholas for being so persistent in putting these symposia together. I think it is a good contribution to have something like this going on. Thank you for coming.

THE WIND ENERGY RESEARCH AND DEVELOPMENT PROGRAM IN CANADA

M.S. Chappell

TM-WE-011

Wind Energy Technical Memorandum - Energy Division
National Research Council of Canada

Overview presented to the Fifth Annual Wind Energy Symposium
Ryerson Polytechnical Institute, December, 1982

This technical memorandum is issued to furnish information. It is preliminary in character, has not received the careful editing of a report, and is subject to review.

TABLE OF CONTENTS

Page

SUMMARY 5

INTRODUCTION 6

1.0 Objectives 7

2.0 Scope and Focus 7

- 2.1 Type of Windmill 7
- 2.2 Forms of Energy Output 8
- 2.3 Size of System 8

3.0 Applications 9

4.0 WERD Program Structure 9

- 4.1 Resource Assessment 10
- 4.2 Fundamental Research 12
- 4.3 Testing and Field Trials 13

Concluding Remarks 20

References 21

THE WIND ENERGY RESEARCH AND DEVELOPMENT PROGRAM IN CANADA

M.S. Chappell
National Research Council

SUMMARY

The Canadian Wind Energy Research and Development (WERD) program comprises three major sub-programs:

- (i) resource assessment
- (ii) fundamental research
- (iii) testing and field trials.

The program is administered by the National Research Council (NRC) and technology development is focussed on the vertical-axis Darrieus configuration. Major emphasis is directed toward large-scale systems with electrical output which are believed to have the greatest near-term potential cost-effectiveness.

INTRODUCTION
****

(Preface to verbal presentation at Wind Energy Symposium)

In Canada we have a wealth of energy potential, but presently not all of it cheap, nor all of it technologically retrievable or useable.

As Ken Burkhardt mentioned, there is some kind of security in diversity. In highly technological systems one sometimes discovers considerably later things that weren't apparent at the time the systems were put into place. It is nice to have the knowledge with which to make the decisions at that point in time and not have to go and seek it under the pressure of having to do something right away. We've seen the kinds of problems we can get into with moving too quickly with technology. A current example is the UFFI business which was done with the very best of intentions. It is a good insulation material and has installability features which made it appropriate to retrofit those houses which needed it the most. Just drill a hole and fire the stuff in. There were some reservations from the technical boys - "There are some things we don't understand about this stuff" - but the perceived need and urgency at that time drove us into using a technology which we didn't fully understand. Now we are facing the awkward situation of having to go back and patch up the technology. With UFFI we have to remove the material from houses. Something that was very easy to put in is extremely difficult to take out.

Canada's wind energy R&D program is proceeding bearing in mind this background behind it. We need to develop a knowledge and understanding of the technology. We need a basis for rational and hopefully correct decision-making as to where it might be used now and in the future and to stand in as an insurance policy so that later on if some of our major energy systems come up against some cropper, we'll know what the potential is. We won't blindly say we will switch completely to wind to provide all our electricity. We know enough about it to know that we can't, but we are learning more about where we can use it appropriately.

1.0 Objectives

The broad objectives of the Canadian Wind Energy Research and Development (WERD) program are:

- To determine under what circumstances wind energy can make a viable contribution to Canadian energy supplies.
- To establish the technology of wind energy conversion systems (WECS) appropriate to Canadian conditions.
- To encourage and support Canadian industrial initiatives in the design and manufacture of WECS for both domestic and export markets.

2.0 Scope and Focus

Three parameters which define the scope of the Canadian WERD program are:

- Type of Windmill
- Form of Energy Ouput
- Size of System.

2.1 Type of Windmill

Research at NRC during the 1960's resulted in reinvention of the low-solidity VAWT first patented by George Darrieus in 1927. Subsequent to the oil embargo of 1974, reorientation of the efforts towards larger systems confirmed several attractive features of this configuration. Most of these attractive features related to the precept that a simple arrangement was likely to be most reliable and most cost-effective, particularly during the evolutionary phases of the new technology. Such features include:

- Omnidirectionality - eliminating need for yaw controls and drives.
- Drive train at ground level - especially meaningful for megawatt-scale systems where drive train and generator weigh several hundred tonnes.
- Troposkein blade shape - minimizes centrifugal bending stress and simplifies structural design.

- Stall-control aerodynamics - eliminating need for variable geometry elements to control peak power output at high windspeeds.

2.2 Forms of Energy Output

The direct output of most WECS is shaft power, thus to some extent the final step of the conversion process is irrelevant to the basic WECS R&D. Nevertheless, the characteristics of the energy end-use form do interact with the windmill system performance.

The existence of extensive electrical distribution networks, makes aeroelectricity the logical form for integrating large scale contributions of wind energy into Canadian energy supply systems. The same reasoning applies to isolated communities now served by diesel generator sets, where random aeroelectricity inputs permit throttling-back the on-demand powerplant. For very small power demands in remote areas, the problems and costs of storage can be less than those of connection to the closest existing grid. Currently, this applies only to isolated systems with very small average power outputs.

2.3 Size of System

Studies have shown that, at sizes below the megawatt range, certain factors offset the usual performance/cost "square/cube" relationship and tend to increase the costs of smaller systems. These factors include higher proportional costs of fabrication, electrical generators, control systems, and site work, as well as reduced output because of lower wind speed nearer ground level. Hence the current emphasis is on large, grid-coupled VAWT generating systems. Often the field trial activities in the WERD program serve two purposes simultaneously - a single VAWT system could represent a small-scale model of a multi-megawatt unit and a full-scale prototype of the VAWT component of a remote community power supply.

In summary, the emphasis of the current Canadian WERD Program is focussed toward large-scale, grid-coupled, Darrieus VAWT electrical generation systems.

3.0 Applications

Canadian applications for aeroelectric systems can be grouped as follows:-

Special Purpose (communications) (navigation aids)	- 1 kW (DC) single unit installations - on-demand power (require storage) - reliability (remote, no back-up) - expensive: $10,000/kW
Remote Community (northern Canada) (isolated areas)	- 100 kW (AC) single-unit installations - local network - no storage - coupled to (diesel) base - fuel saving mode operation - $1500/kW (15 cents kWh)
National Energy (utilities)	- 10,000 kW (AC) mult-unit installations - grid-coupled - no storage - fuel saving plus capacity credit - $500/kW (5 cents/kWh)

Note that unit sizes differ by two orders of magnitude between each category. Only megawatt-scale installations are likely to provide a measureable contribution to national energy supply systems.

4.0 WERD Program Structure

Like most national wind energy R&D programs, the Canadian program comprises three major sub-programs:

- * Resource Assessment
- * Fundamental Research
- * Testing and Field Trials

The primary elements in each of these sub-programs are listed in TABLE I and the highlights are elaborated in the subsequent paragraphs.

TABLE I : Canadian Wind Energy R&D Program Elements

Resource Assessment

- Co-ordination of existing data
- Analytical and experimental modelling techniques
- Calibration and deployment of wind measuring instruments
- Site evaluation and assessment of wind energy potential

Fundamental Research

- Analytical and experimental aerodynamics of airfoils and
- rotors
- Aeroelastic modelling and testing
- Development of structural dynamic design methods
- System performance and economic predictions
- Investigation of alternative energy extraction techniques
- Technical support of major wind energy studies

Testing & Field Trials

- Wind tunnel calibrations of small commercial wind turbines
- Support of Atlantic Wind Test Site, P.E.I.
- Six stand-alone systems (special applications)
- 10 kW and 100 kW wind/diesel hybrids
- Four 50 kW grid coupled units (remote community applications)
- One 230 kW grid coupled unit (grid-scale energy supplies)
- Design, construct and evaluate megawatt-scale turbine (Projet EOLE)

4.1 Resource Assessment

Correlation of long-term weather data [1]* has identified general regions of good wind energy potential as illustrated in Figure 1.

---

* numbers in square brackets relate to References listed at the end of the paper.

Such generalized wind energy information has two major drawbacks:-

a) It is compiled from measurements taken at locations chosen for other-than-wind-energy reasons, and hence is probably conservative.

b) Local terrain features influence the wind velocity, hence the wind energy potential at any site is strongly dependent on mesoscale topography.

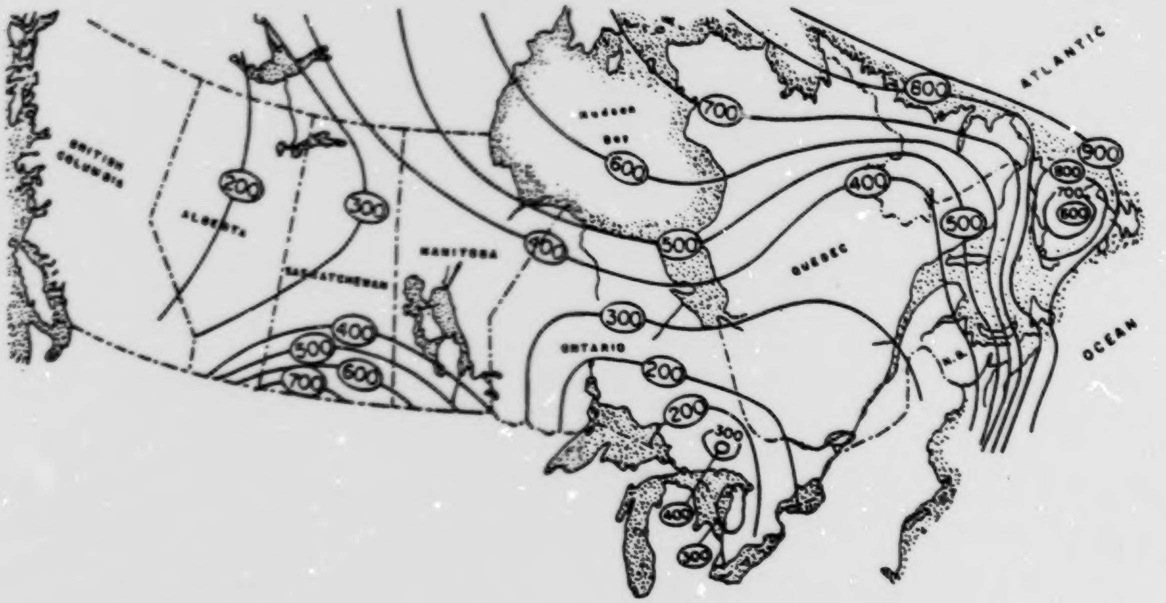
ATLANTIC
OCEAN
HUDSON BAY
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
ONTARIO
QUEBEC
N.B.
800
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Figure 1. Annual Average Wind Power Density at 50 m (W/m^2)

Consequently, analytic methods are being developed by the Atmospheric Environment Service of Environment Canada to interpolate between existing measuring stations, taking account of intervening terrain features to as great an extent as possible. Ultimately, WECS site assessment must be verified by actual measurements, preferably over about one year to include seasonal variations. NRC co-operates with potential commercial and utility users of wind energy by loaning self-contained wind histogram recorder systems. The potential user installs the system and gathers data on a weekly of monthly basis. NRC analyzes the data and provides an assessment of the site potential in relation to the user's proposed application. Approximately 30 such instrumentation packages are now deployed.

about half at existing turbine sites and the remainder at potential new sites.

4.2 Fundamental Research

Analytical prediction of Darrieus VAWT performance is well advanced based on Templin's Double Multiple Stream Tube method that accounts separately for the "front" and "back" blades. Further experimental and analytical work is underway to examine the dynamic stalling characteristics of symmetrical uncambered NACA airfoils in hopes of improving performance prediction in the stall-controlled region.

The Darrieus rotor is a complex aeroelastic rotating structure, subject to a variety of dynamic and periodic loads. Its many vibrational modes and resonant frequencies must be determined and controlled to avoid high stresses and fatigue. Dynamic analyses of the rotor-guy system are being developed at NRC and in Canadian industries.

Several WECS systems analysis studies have been carried out. Templin at NRC examined the effects of several design variables on VAWT energy capture [2,3]. A major parametric study by Shawinigan Engineering [4] examined the design and cost of 72 VAWT systems representing combinations of values for the following parameters:

Swept Area (A):	1000 m^2 to 8000 m^2
Rotor Height to Diameter Ratio (H/D):	1.0 to 2.0
Solidity (Nc/R):	.05 to .30
Number of Blades (N):	1, 2, and 3
Equatorial Height to Rotor Height Ratio:	0.5 to 1.0
Installed Power to Reference Wind Power Ratio:	0.5 to 2.0

The study concluded that electrical energy could be generated by production megawatt-scale grid-coupled VAWT's at 1978 costs of 4 cents/kW-h. Another major study by Shawinigan compared the relative technical and economic merits of HAWT and VAWT megawatt-scale grid-coupled systems at projected equal states of development [5]. The conclusions were that, although VAWT technology is currently behind HAWT technology, when both are commercially mature the Darrieus troposkien VAWT has a slight technical and economic advantage.

Experimental work on NRC and commercial WECS models has been performed in several of NRC's wind tunnels, including the (1.92m x 2.74m) research tunnel and the larger (9.15m x 9.15m) tunnel. To achieve accurate results quite different model scales must be used for performance and for aeroelastic investigations.

Work has begun on the development of safety, performance, and durability standards for small WECS at the Canadian Standards Association (CSA). This effort is being co-ordinated with similar activities underway at the American Wind Energy Association (AWEA).

4.3 Testing and Field Trials

An outdoor facility, the Atlantic Wind Test Site (AWTS) has been established on Prince Edward Island to enable performance and durability testing of SWECS under realistic operating conditions. Testing of production machines, as well as experimental units, is undertaken on a commercial basis.

Twelve field trial installations have been initiated as co-operative projects involving the WERD program and potential Canadian users of WECS technology. The objectives of these projects are:-

- to provide performance and durability data under realistic operating conditions and to verify analytical and design techniques.
- to provide operating experience to aid users in assessing the characteristics, applicability and technical maturity of WECS systems.

TABLE II "Special Purpose" Field Trial Installations

Location	Partner Agency	System Rating	Application	First Commissioned
Calgary. Alta.	Shell Oil Co.	2.8 kW at 26 kph	Cathodic Pipe Protection	May 1979
Edmonton, Alta.	Alberta Gov't Telphone	0.8 kW at 23 kph	Telecommunications Relay	July 1979
Lumsden, Sask.	Saskatchewan Telephone	2.8 kW at 26 kph	Telecommunications Relay	June 1979
Maryborough Ont.	CN/CP Telecommunications	2.8 kW at 26 kph	Telecommunications Relays	(August 1981)
Sackville N.B.	Cdn. Broadcasting Corp.	0.8 kW at 23 kph	Broadcast transmitter	(August 1981)
St. John's Nfld.	Newfoundland Telephone	2.8 kW at 26 kph	Telecommunications Relay	(August 1981)

Six "special purpose" field trial units have been installed as shown in TABLE II. These systems, designed and built by Bristol Aerospace Ltd., comprise a combined Savonius-Darrieus rotor (for aerodynamic self starting in low winds), a shaft-speed permanent magnet alternator (for simplicity and low starting torque), control and rectification circuits, and sufficient battery storage for maximum anticipated periods of calm. Data from most sites is transmitted via satellite for processing at the manufacturer's plant.

Following a preliminary 10 kW experiment in 1978 and further system/economic studies [8], a 100 kW hybrid wind/diesel field trial installation was commissioned in January 1982 at Sudbury, Ont. The 17m x 11m VAWT is mechanically coupled to a 50 kW diesel-electric set as part of a prototype 100 kW remote-community powerplant. The project includes accurate calibrations of the individual components of the powerplant package as well as detailed assessments of the effects of the wind turbine on the load-following duty cycle of the diesel engine and the ramifications on diesel operating economy and maintenance requirements.

Four 50 kW VAWT systems have been purchased by NRC from DAF Indal Limited for co-operative field trial assessments with provincial electric utility agencies (TABLE III). These systems each comprise a 17m x 11m Darrieus constant speed rotor mounted on a 10m tower and supported by guy cables, a speed-up gearbox, a 60 cycle induction motor/generator, and controls for automatic operation and protection. They are directly coupled via appropriate transformers to the local electrical distribution networks.

TABLE III: 50 kW Grid Coupled Field Trial Installations

Specifications:		
	Rotor	17m x 11m (125 m^2)
	Power	50 kW at 15.2 m/s
	Energy	80 MWh/yr

Partners:

Partner	Location	Commissioned
Newfoundland and Labrador Hydro	Holyrood, Nfld.	June 1978
Saskatchewan Power Corporation	Swift Current, Sask.	August 1978
B.C. Hydro	Victoria, B.C.	November 1980
Churchill Research Centre	Churchill, Man.	October 1981

Experience:

* Holyrood logged 4000+ hours generation, now returned to NRC for detailed inspection, being replaced (at NLH request) with updated unit.

* Swift Current (highly instrumented) mainly experimental running, utility evaluation begins early '82.

* Victoria now consistently over 90% availability full unattended running since Sept. '81 (2000 hr., 25 MWh to end of October '81).

* Churchill commissioned October '81 and turned directly onto automatic: climatic test machine for northern applications.

Results:

* Verification of performance predictions
* Control problems elucidated and rectified
* Superior brake/gearbox designed
* Strengthened industrial competence
* Enhanced utility interest

The 230 kW field trial unit on the Magdalen Islands (see TABLE IV) was first erected in 1977 as a joint NRC/Hydro-Quebec project. After a year of commissioning and preliminary testing [9, 10] the 37m x 25m rotor was destroyed and a second (highly instrumented) rotor of similar design was operational in early 1980. Testing over most of the operational range has now been completed [11] and further experiments are focussed on verifying analytic techniques and design concepts for Project EOLE.

TABLE IV: 230 kW Grid Coupled Field Trial Installation

Specifications:
Rotor 37m x 25 m (595 m^2)
Power 230 kW at 13.4 m/s
Energy 400 MWh/yr

Location: Magdalen Island, Gulf of St. Lawrence

Partner: IREQ (Hydro-Quebec)

Experience:

First Operation 1977

Highlights:
- Operation up to 86% design speed
- Performance better than predicted
- Data on guy vibrations
- Preliminary stress data

6 July 1978:
- Failure occurred after operation at nearly twice design speed for over one hour
- Primary cause procedural
- Mechanical integrity and basic design confirmed

Rebuild:
- Rotor and guys only (to original design)
- Addition of low speed shaft braking system
- Upgraded instrumentation

Test Status:
- Recommended January 1980
- Confirmed previous performance data
- Extensive dynamic stress data
- Operation at 100% design speed
- International participation
- Current test program complete Mar. 82

Future: EOLE testbed
HQ generator

DAF Indal Ltd., manufacturers of the 50 kW and the 230 kW field trial units, have designed a production level model VAWT system based on the Magdalen Island machine. The commercial unit employs the single mesh gearbox and hydraulic rotor support system developed on the latest 50 kW installations. Figure 2 and Table V give details of this configuration. Initial deliveries are scheduled for late in 1982.

Figure 2 - DAF Indal VAWT Power Module

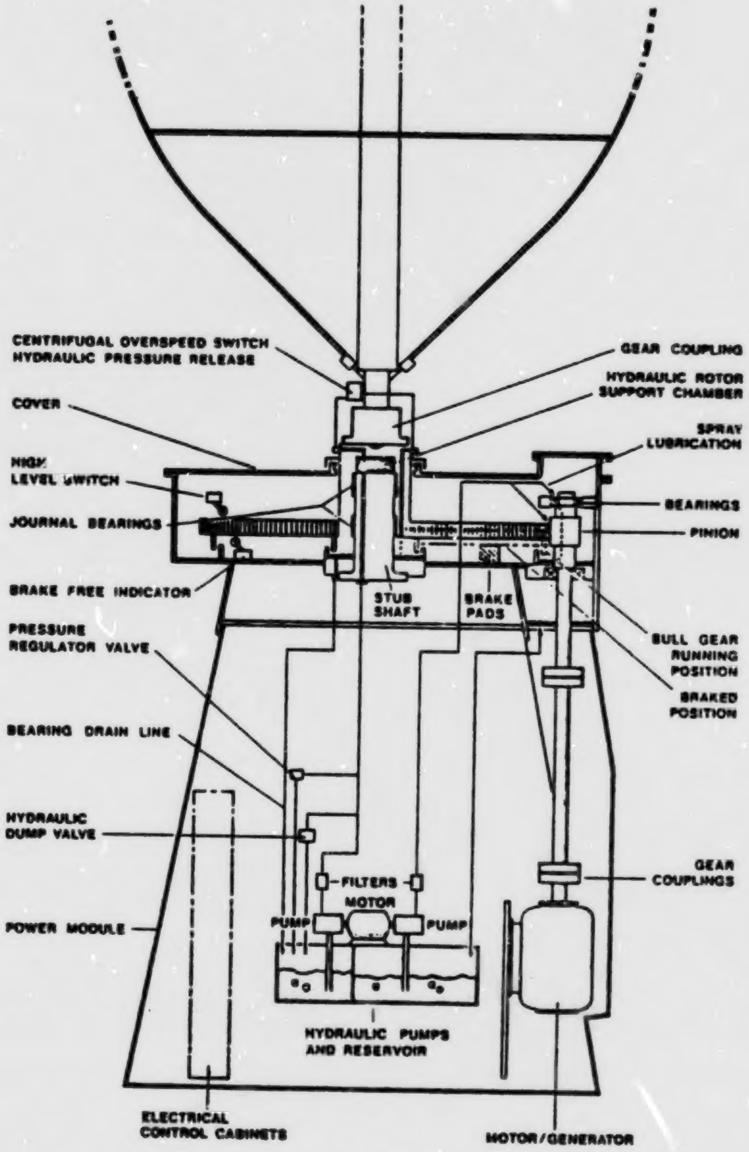
CENTRIFUGAL OVERSPEED SWITCH
HYDRAULIC PRESSURE RELEASE
GEAR COUPLING
HYDRAULIC ROTOR SUPPORT CHAMBER
COVER
SPRAY LUBRICATION
HIGH LEVEL SWITCH
BEARINGS
JOURNAL BEARINGS
PINION
BRAKE FREE INDICATOR
STUB SHAFT
BRAKE PADS
PRESSURE REGULATOR VALVE
BULL GEAR RUNNING POSITION
BRAKED POSITION
BEARING DRAIN LINE
HYDRAULIC DUMP VALVE
FILTERS
MOTOR
GEAR COUPLINGS
POWER MODULE
PUMP
PUMP
HYDRAULIC PUMPS AND RESERVOIR
ELECTRICAL CONTROL CABINETS
MOTOR/GENERATOR

TABLE V: DAF Indal Series 6400 Model 500 VAWT System Specifications

Rotor Height	120	ft	(36.6 m)
Rotor Equator Diameter	80	ft	(24.4 m)
Blade Chord	29	in	(0.74 m)
Length of Blade (NACA 0015)	142.4	ft	(43.4 m)
Blade Root Elevation	12.4	ft	(3.78 m)
Swept Area	6,400	ft^2	(595 m^2)
Rotor Column Dia. (Ends/Centre)	3/5	ft	(.9/1.5 m)
Rotor Weight	33,740	lb	(15,300 kg)
Rated Electrical Output	500	kW	
Rated Wind Speed at Equator	43	mph	(19.2 m/s)
Rotor Speed	45	rpm	
Braking Torque Capacity	200,000	ft/lb	(271,200 n/m)
Induction Generator Rating	2 at 350	HP each	

Formal approvals have been received for the construction of a megawatt-scale grid coupled VAWT prototype. Dubbed "EOLE", the project is a co-operative, cost-shared undertaking Hydro-Quebec and NRC, whose major objectives are:

- To confirm the technical feasibility of megawatt-scale VAWT generator systems.
- To evaluate the design and to determine the operating, performance, and control characteristics of megawatt-scale VAWT generator systems, and their interactions with the recipient electrical network.
- To verify analytical techniques used for the aerodynamic and structural design, and to indicate economic potential of VAWT generator systems.
- To generate knowledge and experience of value to Canadian users and manufacturers of VAWT generator systems.

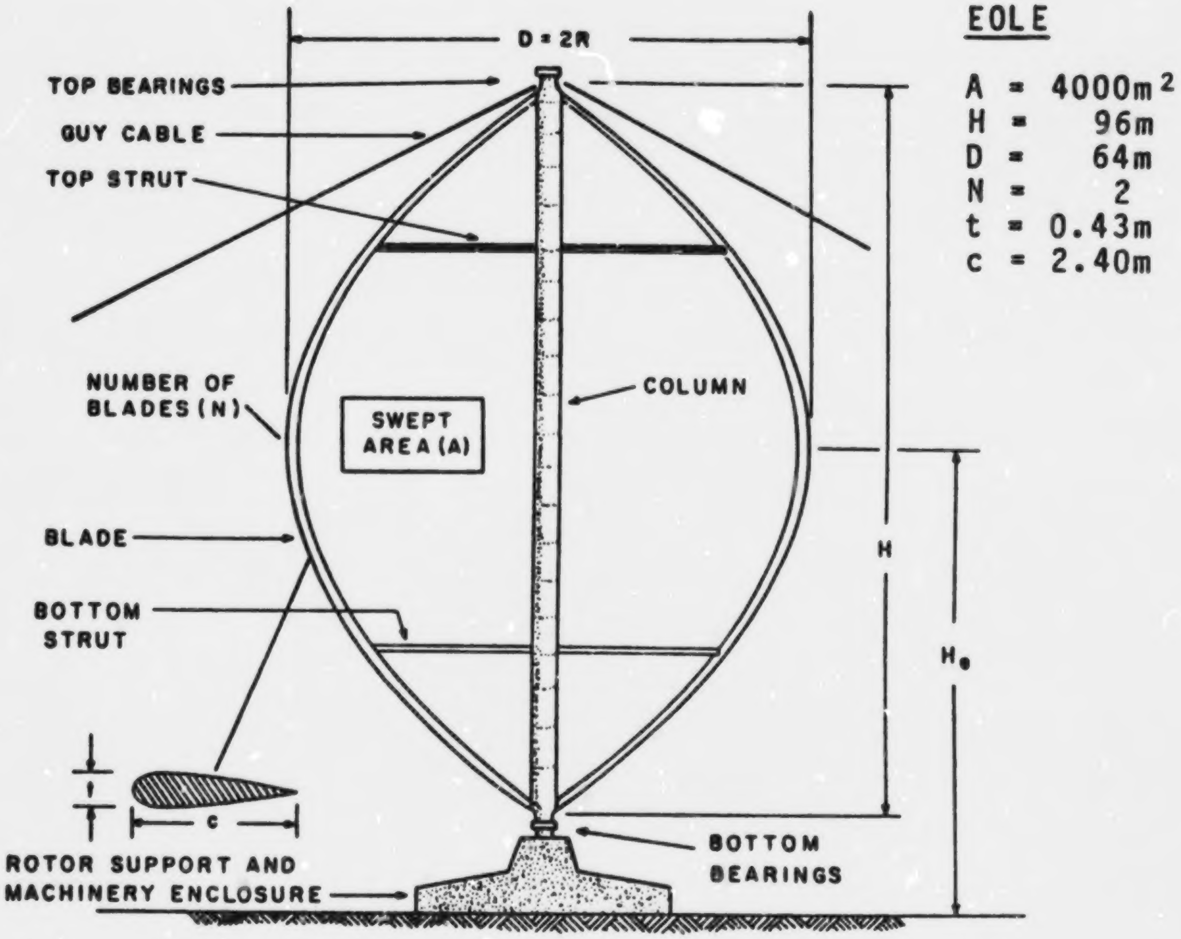
D = 2R
TOP BEARINGS
GUY CABLE
TOP STRUT
NUMBER OF BLADES (N)
SWEPT AREA (A)
COLUMN
BLADE
BOTTOM STRUT
t
c
ROTOR SUPPORT AND MACHINERY ENCLOSURE
BOTTOM BEARINGS
H
H₀
EOLE
A = 4000m²
H = 96m
D = 64m
N = 2
t = 0.43m
c = 2.40m

Figure 3: EOLE - Preliminary Specifications

Preliminary specifications for EOLE have been established based on comprehensive systems studies [4, 5, 12]. EOLE will have two troposkien-shaped blades encompassing a swept area of 4000 m^2 (see Fig. 3). The airfoils will be NACA 0018 section with 2.4m chord. Rated output will be about 3 MW, depending on which site is chosen. Six sites are under consideration, five in the St. Lawrence Valley and one on the Magdalen Islands. Four of these candidate sites have been instrumented to obtain wind data up to 60m (the approximate mid-height of EOLE's rotor).

A comprehensive dynamic mathematical model has been developed by Shawinigan Engineering to aid in the design of EOLE. Preliminary design is now underway and detailed design is expected to require most of 1982. Fabrication and assembly will be completed in 1983 and erection and commissioning is scheduled for the summer of 1984.

Concluding Remarks

VAWT technology is currently at a similar state of development as was the automobile prior to the introduction of Ford's Model T. It has been established that the concept works. Experimental units and limited preproduction prototypes have verified the fundamental performance characteristics. Manufacturing technologies have been established and verified for machines up to 1/4 MW. Cost projections for realistic production quantities suggest economic viability. Nevertheless, many important technical considerations still require further investigation.

VAWT system dynamic simulation programs are needed to allow detailed examination of alternatives in powertrain configuration, control system philosophy, and interactions with the recipient electric network. Significant use can be made of instrumented VAWT field trial systems to provide physical verification of these analytic techniques.

To date, windmill field trials have involved only individual units, yet it is foreseen that major contributions of wind energy will come from arrays of such machines. Hence, it is necessary to determine the effects of both aerodynamic and electrical interaction among the members of the array [14] and with the grid network it is supplying.

The decision to proceed with a megawatt-scale experimental VAWT system is a major milestone in the WERD program.

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12b. SUPPLEMENT TO PROJECT DEFINITION WORK (1980) - Shawinigan Engineering Company Limited, June 1980.

13. CALIBRATION AND TESTING OF THE DAF Indal WIND HISTOGRAM
P.J. Penna, National Research Council, Wind Energy Technical Memorandum, TM-WE-002, January 1981.

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R.J. Templin, National Research Council of Canada (LTR-LA-171) June 1974.

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Bill Stewart, P.Eng.
Remote Power Group,
Ontario Ministry of Energy

Renewable Energy has received renewed attention in the last decade mainly because of the awareness that fossil fuels are being depleted and are becoming more costly to extract. There are also many advantages to using renewables including reduced or negligible pollution, reduced environmental impact in terms of land degradation, lower or zero fuel costs, and, in many cases, the ability to generate near the point of use. Windpower, for example, excells in all of the above. With all of these advantages, why are renewables not developing as quickly as they could?

There appear to be two main obstacles preventing the direct adoption of many of the renewable options. They are:

1) high initial cost,
and 2) questionable reliability.

Are there then strategies that can be employed to overcome these obstacles?

Cost reductions can be achieved through proper technical development and effective marketing. Large volume sales of units can significantly decrease the unit costs from that of the original prototype; and to increase sales, potential users must be first convinced of the performance and reliablility of the systems. As well, operating costs should be kept to a reasonable low if the systems are functioning properly.

The economics of systems are not solely related to initial cost. The "payback period" of a system is also influenced by the energy cost environment in which it is placed. High cost renewable systems can often look quite attractive in locations where conventional energy costs are high. Examples of such locations are remote communities in the north. Remote locations can, therefore, provide the needed environment to develop renewable systems.

Reliability is the other factor which has restricted the adoption of renewables. Reliability in terms of supply of the feedstock is something which has to be lived with. However, reliability of the systems themselves must be demonstrated and documented if we are to dissolve the common impression that renewable systems such as solar and wind are very unreliable.

How is the Ministry of Energy responding to these problems?

The Ministry of Energy has set a number of objectives towards which its various programs are aimed. These include:

1) Reducing the consumption of oil base fuels through the adoption of conservation techniques and the use of alternate and renewable energy sources.

2) Increasing the renewable energy contribution to 5% of Ontario's primary energy needs by 1995.

3) Aiding industry in the development of marketable renewable systems for use in this country and abroad.

There are three main components which the Renewable Energy Group of our Ministry uses in developing and promoting renewable energy sources. These are:

1) Assessment of the technology or the site specific application of the technology. This includes assessment of locations for effective demonstration and implementation of systems, site specific feasibility studies and in-house evaluation of systems and proposals.

2) Public demonstration of commercial systems coupled with monitoring of systems parameters and performance evaluation.

3) Information transfer to the public through news releases, advertisements, and the publication of pamphlets, user handbooks and technical reports following projects.

With programs based on these components, we feel that we can help in moving renewable energy systems from the prototype stage to commercialization and also identify locations and applications where they can be best utilized.

Related specifically to windpower, the Ministry is involved in small and medium scale demonstrations, the production of a user handbook and publication of last year's Ryerson Wind Symposium proceedings.

Phase I of the Sudbury wind-diesel demonstration project is nearing completion with submission of the final report. In this project, a 35 kW Darrieus vertical axis wind turbine was mechanically coupled to a 50 kW diesel generator and run in conjunction with a backup diesel to supply power to a programmable load. Fuel savings were predicted (and demonstrated) to be between 10 and 25% depending on the wind regime.

In carry-on to the Sudbury Phase I project, Phase II will modify the system to allow the wind generator to run independently of the diesel and also to allow the wind generator to be retrofitted to existing diesel plants. It is expected that this will further increase fuel savings to total 15 to 40%. At almost $1.00/litre for diesel fuel in the far northern reaches of Ontario, annual fuel savings of up to $25,000 can be achieved for a 100 kW system.

The Sudbury wind-diesel program is being supported by our Ministry, the National Research Council of Canada, Energy, Mines and Resources Canada (in Phase I), Ontario Hydro and the Contractor, DAF Indal Ltd.

Our Ministry is also involved in a 10 kW stand-alone wind power system demonstration, for remote, but smaller applications. The system will be sent out to the Atlantic Wind Test Site in P.E.I. for one month performance testing. Following successful testing it will be brought back and installed for public demonstration at the Kortright Centre for Conservation north of Toronto. The Metropolitan Toronto and Region Conservation Authority owns and operates the Centre and the wind system will be integrated into their public education program. J.R. Ball is the manufacturer of the system.

There are an increasing number of people becoming interested in windpower as indicated by the number of inquiries we receive at the Ministry. Many are quite interested but lack the knowledge and tools to make an assessment of the appropriateness of windpower to their own situation. In response to this, we are preparing a windpower user handbook to help in assessing the energy delivery and economics of a particular windpower system. The book will contain methods for calculating energy, storage capacity and life-cycle costs, and will also contain lists of manufacturers and distributors, wind data and appliance demand data: thus presenting the user with most of the items necessary to make an overall assessment.

For the near future we plan to extend our windpower program with continued testing and demonstration of Canadian machines and transferring information from our studies to the public. In this way we hope to aid the development of viable systems for remote applications today and for non-remote applications in the future when conventional fuels become more costly.

Questions:

Q How many requests from the public on wind energy are you averaging?

A Two - three per week.

Q What information. are you currently supplying?

A For general interest questions we have a package which we send out which contains lists of manufacturers, distributors and their contacts, a few general biblographies. For specific requests we try to respond to them directly - required technical info and so on.

Q How will your publication differ from the one put out by the Ministry of Energy in Nova Scotia - Power from the Wind. Which covers pretty much the same areas which you have talked about.

A Their's is a small pamphlet that covers the basics of windpower and gets the reader familiar with what windpower is all about. Ours is more a user handbook that will allow them to actually get in there and do some calculations of how much energy a particular system will deliver, what the costs are, etc. It will not be complete enough to make a detailed assessment of all the costs that are required, but to the point where they can make some valid decisions.

Q When is the handbook available?

A We hope early next spring, its been in the works almost a year and a half now.

Q Do you have to get involved in fairly detailed calculations regarding wind if somebody is interested in setting up but has made the first couple of steps but is stuck there and doesn't have the money to get a professional engineer or whatever?

A We'll give them as much information as we can based on our experience or refer them to manufacturers via lists and suggest they get in touch with them for details on specific systems.

Q What is the Canadian content requirement before you'll get involved with a manufacturer or distributor in terms of testing. For example, would you get involved in testing a machine where the initial prototypes were not made in Canada but which would be made in Canada in the future.

A Yes. I think so. We're interested mostly in Canadian manufactured machines. However, if there is an indication that foreign machines will be manufactured here, then we will consider them.

Q What parameters are you monitoring in these demonstration systems? What values are you getting out?

A Sudbury wind-diesel has extensive monitoring. Everything from wind speed power output, torques on a continuous basis. On smaller systems will be limiting it to average wind speeds and accumulated energy output. When we send the smaller unit to P.E.I. there will be more extensive monitoring. i.e. electronic digital recording of various parameters.

Q So, you're not getting into, for example, strain guage measurements on any of the turbines?

A There will be some of that at the Atlantic Wind Test Site. Not in our demonstrations though.

Q Is there some kind of a display panel at the site for public information purposes at Kortright?

A Yes. There will be a general sign plus a technical paper for handouts.

Q Will the display monitor wind speed and power output?

A Some monitoring but for experimental purposes rather than display. The Kortright centre will be setting up various educational programs and will want to monitor various things so they will be flexible in this.

Q What kind of budget does OME have?

A This year we had about $300,000 to spend on our wind power program. For our Remote Power Group programs, which also include small hydro, wood gasification and other things, there is a total budget, including wind, of just under $800,000 this last year.

Q I presume then that your onus is on small machines as opposed to very large machines?

A Yes, small to medium machines because we are looking primarily at remote applications.

Q What is the interest in a wind energy technology test facility here in Ontario? Although the site in P.E.I. is excellent and they've done a good job of instrumentation it is still a long way to go and hence, expensive. There are strong winds locally, for example, on the landfill Leslie Street Spit that stretches into Lake Ontario east of the Toronto Islands or Main Duck Island in Lake Ontario. What is the interest to bring that kind of facility a little closer to Ontario?

A We've been thinking about the Sudbury site, in fact. Whether it would be worth keeping it going as a possible joint operation between ourselves, NRC, and Ontario Hydro and whoever is interested in using it for testing.

Q Would the CSA eventually get into that?

A (Roy Patterson) Not on a program basis. CSA stays in the standards and certification area. They have enough on their plate in those two areas. I think you're thinking of trying to maintain an area or look at it as a certification spot. In the case of wind energy we'll be possibly certifying but at sites already set up.

Q Is there a standard ready?

A (Roy Patterson) No, not yet.

Q Is there a standard committee?

A (Roy Patterson) Yes, a couple of them.

Q When is the Kortright centre open and available?

A January - February, the system will be set up.

Q The 10 kw machine is horizontal or vertical?

A Horizontal, 3 blade.

Q There are rolling hills at the Kortright centre, presumably you'll put the machine on top of one rather than in the valley.

A Yes. Away from trees and buildings.

THE ROLE OF THE CSA IN DEVELOPING STANDARDS: STATUS REPORT ON WECS STANDARDS

- Roy Patterson,
Canadian Standards Association

Work Backgrounder:

Originally from Ottawa, Mr. Patterson received his B.Sc. in mechanical engineering at Queen's University before joining Canadian General Electric (CGE) in 1947. He completed their well known engineering test course a year later. At CGE, his efforts included basic design of protective equipment in residential wiring products for which he received 3 patents for basic design improvements. At mid-career he was manager of engineering, responsible for the output of a group of professional engineers and technicians in the design and development of wiring products. In the later part of his career he directed the efforts of a group of professional engineers and technicians on wiring and heating products.

Presentation:

I could tell you the Canadian Standards Association is a large, voluntary, not-for-profit, national organization made up of business, government, labour, consumers, and other related associations. That it has been preparing standards for more than 60 years and providing certification for almost 40. That nearly 6,000 people serve, on a voluntary basis, on over 1,000 standards committees. I could review a very important function, the testing and certification service and the CSA certification mark which now appears on more than half a billion products sold each year in Canada, including not only the well known electrical products:

- Clothes Washers and Ranges.

But also less known products such as:

- Heat pump
- Gas can
- Plumbing equipment
- Helmets
- Bicycles
- Solar panels

In Solar we are starting to set up the standards and actually test solar panels.

Of the more than 600 people employed by the CSA at our head office in Rexdale, something like 10% are employed in standards work. Testing and certification service is the major part of the CSA work in monetary terms. Out of this office we do the certification work for the manufacturers in their particular areas.

The inspection service is global in scope. These are all important facts about CSA - It's what CSA is. But more important than what we are, is the question of how we are perceived to be.

How do people on the outside view the role of CSA in developing standards versus the real-life situation? It's like the head you often seen in lighting exhibits in which the facial features change very radically depending on the lighting - so too is CSA viewed and identified.

CSA is often identified as a government agency - it is not. It is entirely self-supporting through certification work, sustaining memberships, and the sale of standards. We accept government contracts to do specific work which is audited by the government. The majority of my work, for example, relates to government contracts on ENERGUIDE and Wind Energy Conversion Systems but this is an exception rather than the rule. These contracts can be cancelled and this ensures that the development of CSA standards receives government input but is not government controlled.

Standards are often considered a road block to the development of new products. They are not. There is no question, the method used to reach agreement on the content of a standard is time consuming but once a standard is developed it is of benefit to everyone concerned including the manufacturer. Standards are beneficial for product development, for obtaining insurance on products, or when going to the bank to borrow money. The CSA is not an organization working just for the benefit of Canadian manufacturers although manufacturers provide a large part of our funds through payment for certification work and sustaining memberships and make a major input in the development of standards.

CSA work is sometimes viewed as a big meat grinder into which you dump a lot of ideas and out comes a standard. It's not so. Some original ideas may be so completely revised that they are hardly recognized in the final standard.

In summary then, CSA standard developments are identified in many ways and, surprisingly, may be all of these depending on how you view this work.

It is government supported - but no more than by all other groups interested in developing standards. If you can accept the time needed to develop a good standard it can be beneficial to all concerned; it is not just the manufacturer who benefits. It is a melting pot, consensus process that takes the ideas of many different concerned groups and melds them into a working, reliable, standard.

The operative work in all this standard work is 'consensus'. Advocated by the CSA President John Kean, 'consensus'-style setting of standards by the private sector is an emerging alternative to much direct regulation by government. The results of setting standards by consensus are cost effective and ensure wide acceptance of the standard.

CSA's major role, to ensure that consensus is reached in standards development, is to maintain a balance between the many interested groups that form the more than 1,000 committees. Figure 1 shows that the CSA itself has been organized with this same balance in mind.

The Standards Policy Board appoints steering committees for all these different groups. These thousand standards committees report to specific steering committees. Each steering committee has a general interest area, for example, the Committee on the Performance of Electrical Products. In this example, you have four working sub committees where work is actually done. The steering committee is the first area where you get financial responsibility set up under CSA for actual work done within that group of standards.

To give a better appreciation of the time to develop and implement WECS standards, I will first refer to a group of Performance standards that were developed over the last five years known as the ENERGUIDE program. This allied conservation program was conceived early in 1977 as an alternative to the high energy growth rates accepted up to that time and the attendant high cost of maintaining those high rates of growth.

With a contract from Consumer and Corporate Affairs Canada (CCAC) a technical committee was set up under the steering committee on Performance of Electrical Products (SCOPEP), comprising manufacturers, Canadian Electrical Association members, consumers, Canadian Appliance Manufacturers' Association members, retailers, and CSA members who sat down and prepared the first ENERGUIDE Standard - C300 - Capacity Measurement and Energy Consumption Test Methods for Household Refrigerators and Combination Refrigerators - Freezers. This standard was issued a year later in April 1978, and in August 1978 amendments to the Consumer Packaging and Labelling Act made mandatory the labelling of all refrigerators and combination refrigerator-freezers sold in Canada.

In succession, over the next three years, the remaining five majors appliances followed a similar format ending up with the mandatory labelling of clothes-dryers in April 1982.

CSA was not only asked to provide the standards input, but the certification group was required to build test facilities to approve products to these standards and a surveillance system was set up to independently check product output. These all culminated in the issue of an ENERGUIDE Directory which lists all models of the six major appliances and allows the consumer, retailers, and manufacturers to compare the energy consumption of appliances that are similar in dimension and features.

In order to advertise this program we have developed a videotape of the ENERGUIDE program. To give you some relief from my voice, we will take a commercial break to show "ENERGUIDE".

******Start ENERGUIDE Videotape******

"More than ever energy conservation is on our minds.

Not only is it in our best interest to decrease consumption and increase cost savings, it is a necessity.

Now people are:

- turning down thermostats
- driving more fuel efficient cars
- installing energy savers in the home
- and the list goes on.

We have been overlooking an area of potential savings. Now, thanks to ENERGUIDE, we can determine energy and cost savings in household appliances, for example, refrigerators, freezers, ranges, dishwashers, clothes washers and dryers. One can actually see on the label how much electric energy is consumed by major household appliances. The ENERGUIDE label is easily recognized, so look for it. It lists kw-h/month of electricity consumption for each type and model of appliance. By comparison shopping you can substantially save money in the long run by reducing the amount of energy consumed.

For example, here is the energy consumption comparison chart taken from the ENERGUIDE directory. It shows very clearly how much money you can expect to spend over 10 years for each level of consumption according to the cost/kW-h in your area. To illustrate possible savings through a simple example, consider a 175 kW-h/month appliance which will cost $240 more over 10 years at (4 cents)/kW-h than an appliance which consumes only 125 kW-h/month. That assumes the cost of electric energy remains constant over the next 10 years. The (4 cents)/kW-h is an arbitrary figure, you can find actual cost/kW-h in your area on your monthly electric bill so you can compute your savings.

Remember just a few dollars per month adds up to a lot of money over the average life cycle of an appliance. The potential for substantial dollar savings is definitely there. Its up to you to comparison shop.

ENERGUIDE is an energy conservation and labelling program for major household electrical appliances. It directly benefits you, the consumer, and aside from consumer savings it is a quicker and cheaper way of helping to solve the energy shortage problem as opposed to developing new sources.

Today energy is a key factor in product design and development. In effect, ENERGUIDE is acting as a stimulus to offer the consumer better buys for less operating costs. Refrigerators were the first appliances labelled under the program. There are now over 6,000,000 refrigerators in Canadian homes. They consume the most energy of major household electrical appliances due to their constant use operation. Now the ENERGUIDE program has expanded to include freezers, ranges, dishwashers, clothes washers and dryers. Again, by comparison shopping you can calculate your savings.

The ENERGUIDE program is a joint effort by consumers, industry, utilities and government, initiated by Consumer and Corporate Affairs Canada in 1978.

The CSA played an important role in the ENERGUIDE program. Testing of appliances under the program is carried out by the CSA. Energy consumption figures on the label are calculated by testing units under controlled conditions. This provides a base figure on which to compare consumption levels. Remember though, actual energy use varies depending on individual patterns.

Consumer and Corporate Affairs Canada publishes the ENERGUIDE directory to help you measure the savings. The directory is updated on a yearly basis and provides the energy consumption for each model listed. They are very useful and available at all Consumer and Corporate Affairs Canada offices. All models must undergo the CSA test and manufacturers are responsible for applying the ENERGUIDE label.

Remember when you are buying an appliance, not only are you purchasing the actual unit, but you are also committing yourself to buying the electrical energy that it uses. Over a ten year period, this electrical energy could cost you as much as the original price of the appliance. This sticker, for example, shows that this particular model consumes 175 kW-h/month. With electricity at 4 cents/kW-h in your area the 10 year electrical bill over the 10 year average life cycle will be about $840 and that's assuming the cost of electricity is constant over the next 10 years. This 10 year electrical energy cost calculation formula will tell you what it will cost over the long run. You want to have the definite possibility to cut down on this cost by selecting the unit that corresponds to your needs and consumes the least electrical energy. The yearly directory published by CCAC is a useful pre-purchasing tool to make your choice according to very precise data. Aside from helping you, the consumer, many retailers are finding that the energy consumption figures on the label can be used as a major selling feature. When you're shopping, be sure to look for the label and ask any store person for any information you need. They will be more than happy to assist you in making decisions based on the energy requirements of the various models and sizes.

ENERGUIDE labelling is a regulatory requirement under the Consumer Packaging and Labelling Act. The regulations require an energy consumption label to be prominently displayed on all refrigerators, freezers, ranges, dishwashers, clothes washers and dryers at the time of manufacture. ENERGUIDE is also encouraging manufacturers to continue to reduce the energy consumption of their appliances in order to become more competitive in the marketplace. Manufacturers have endorsed the ENERGUIDE program as it is obviously in the best interest of everybody involved. In fact, manufacturers have produced significant design modifications trying to improve their products with respect to more energy efficient consumption levels. So everyone benefits from ENERGUIDE. You, the consumer, the retailer, and the manufacturer.

Comparison shopping is the key to saving you money. When you consider all of the appliances that you may purchase, bearing in mind rising energy prices, the costs add up. There is no reason to buy in the dark any longer. Now ENERGUIDE acts as a purchasing tool for you, along with the signs that cover the appliance. The energy requirement has become a very important consideration, another dimension in your purchasing decision.

Since the beginning of the program in 1977, millions of dollars of future savings have been assured as a result of the ENERGUIDE impact on appliance design. The ENERGUIDE program is working for you and for Canada as well. We're reducing our energy consumption and saving valuable dollars.

Look for the label, consult an ENERGUIDE directory and comparison shop. ENERGUIDE is an important purchasing tool for you to use when buying appliances. Look for it and use it, its worth it."

*****End Videotape*****

To establish standards for Wind Energy Conversion Systems (WECS) (Figure 2) the Task Force had to first establish a tie-in point with CSA and on June 22nd, 1982 made a presentation to a CSA Steering Committee already established, namely: The Committee on Solar Energy. This committee has recently included WECS in their Scope and are now known as the Standards Steering Committee on Solar and Wind Energy. The Technical Committee was formed before we had formal approval from the Steering Committee and consists of 13 members.

Figure 3 shows the terms of reference That have been developed for the the Technical Committee on Wind Energy Conversion Systems.

The objectives of the Technical Committee are shown in Figure 4.

Two Subcommittees followed from the Technical Committee - one on SWECS Safety and one on WECS Performance. We are planning a third on interconnection to the grid. The task of these committees is to prepare the actual standards.

The Standards for Wind Energy Conversion Systems is a government contract with the National Research Council. Marc Chappell is our technical mentor. Malcolm Lodge of the Institute of Man and Resources is the chairman of the Technical Committee. It was formed even before we had approval from the Steering Committee.

The first subcommittee is the one on safety of the product. This is the standard that would be mandatory that a product would HAVE to pass in order to get a CSA certification and label. Raj Rangi is chairman. We are concerned with the design and operational environment conditions. Notice this is only to 100 kW, i.e. Small Wind Energy Conversion Systems.

Not sure yet if we will make the performance standard mandatory. The Performance Standard applies to all sizes. There will be no limit established on size. Our basic intent is to determine the reporting of the performance characteristics of the unit. We are considering asking the manufacturer to establish a definite decibel value, a discrete value at a specific distance, a specific point upwind and downwind from the product.

Reliability and durability are part of the safety standard, except maybe with reference to performance. So, there are gray areas between performance and safety aspects. Hard sometimes to separate.

Siting will be another standard or some other manner than a specific standard.

What we may end up with is the usual compromise in a consensus system - or we may end up with a little of both.

Although the SWECS safety subcommittee was established earlier it is believed the standard will be published later than the Performance Standard. The Performance Standard is fairly straightforward and will be completed in a year - within the same time frame as the Performance Standards for ENERGUIDE. The Safety Standard is much more complex and the committee may get hung up on the test procedure versus the design criteria. To explain - we are pushing to establish a Safety Standard that will spell out by test alone the safety requirements for SWECS. This would allow the system to be certified and in the case of CSA certification would bear the CSA monogram. This is the ideal situation but it presents many problems, for example, how do you test for the 100 year wind, or for the once-in-a-lifetime hailstorm? A less satisfactory approach is to establish a design criteria and simply design for the 100 year wind or the hailstorm. This procedure usually leads to over-design and tends to control creativity which is one of the last things that the standard should do. All manufacturers are very concerned that a standard in no way restricts their creative ability. For example, a design standard might say that it has to be made of a certain type of steel or that there are so many bolts per foot or square foot or whatever, which tends to stifle creativity.

We may have to compromise between the ideal and the practical and economical and do a little of both. As stated earlier, the ideas we begin with may be completely changed as work progresses.

We have established the Scope of these two standards. Figures 5 and 6 show the close relationship between the safety and the performance of a product.

Because of the CSA dedication to consensus and the need for wide acceptance of standards, there is need for a very rigorous and sometimes time consuming review before it is published. The final draft from the subcommittee is sent out for public review before it is sent on to the technical committee and steering committee for approval.

The Performance Standard on Wind Energy Conversion Systems should be available for a public review early in 1983 with the objective of publishing later in the year.

Figure 1: CANADIAN STANDARDS ASSOCIATION
ENERGUIDE Organizational Structure

Canadian Standards Association

A voluntary national organization made up of business, government, labour, consumers and associations.

Standards Policy Board

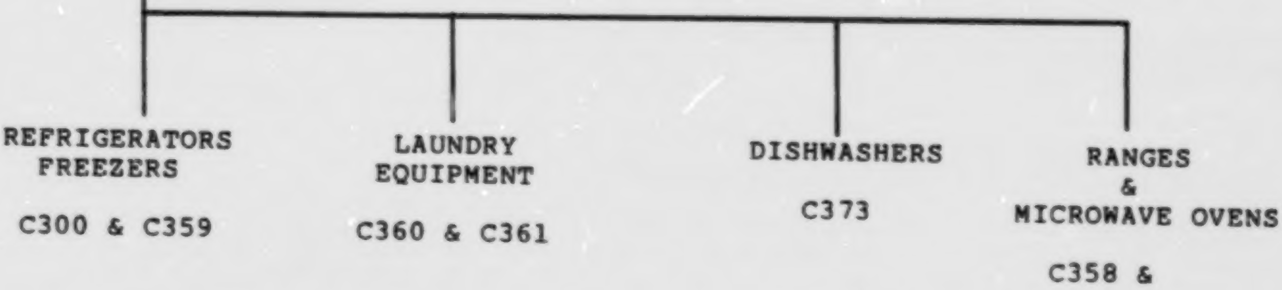
30 Members appointed by and responsible to the CSA Board of Directors made up of a balance of producer, user, Regulatory Authority and general interest.

Standards Steering Committee on the Performance of Electrical Products

SCOPEP - Covers the broad area of Performance of Electrical Products. Established by the Standards Policy Board. Membership will have a reasonable balance from producer, user, Regulatory Authority and general interest. Usuall includes Technical Committee Chairman.

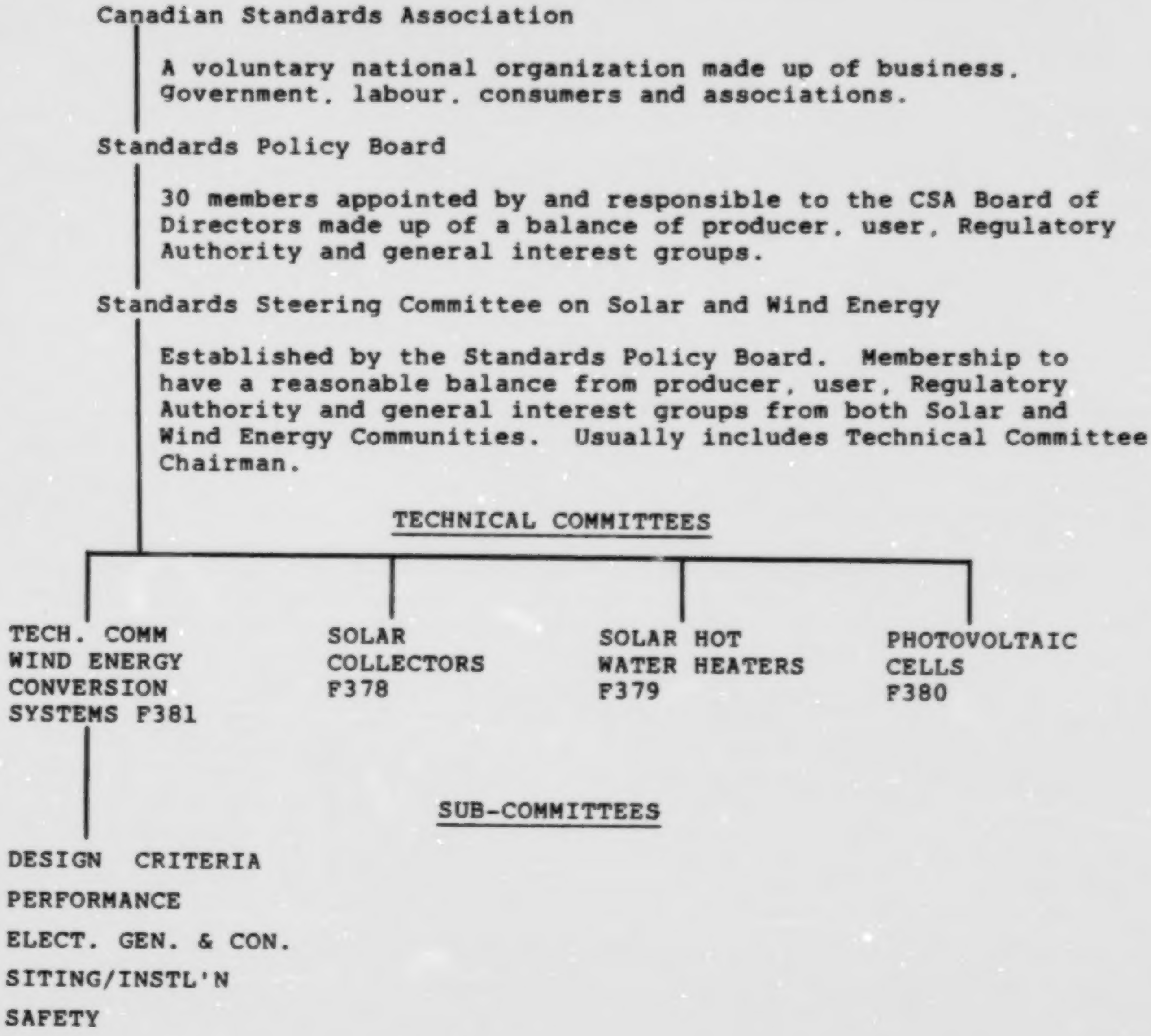
Technical Committee on Performance of Electrical Products

TECPEP - Responsible for the technical content of standards. Established by Steering Committee, the membership should have similar balance. Usually includes subcommittee Chairman.



Sub-committee - Responsible for providing technical knowledge, ideas and experience towards development of standards. Should reflect a national consensus of producers, users, regulatory authorities and other interests.

Figure 2: CANADIAN STANDARDS ASSOCIATION
As related to Solar and Wind Energy Standards



Canadian Standards Association

A voluntary national organization made up of business, government, labour, consumers and associations.

Standards Policy Board

30 members appointed by and responsible to the CSA Board of Directors made up of a balance of producer, user, Regulatory Authority and general interest groups.

Standards Steering Committee on Solar and Wind Energy

Established by the Standards Policy Board. Membership to have a reasonable balance from producer, user, Regulatory Authority and general interest groups from both Solar and Wind Energy Communities. Usually includes Technical Committee Chairman.

TECHNICAL COMMITTEES

TECH. COMM
WIND ENERGY
CONVERSION
SYSTEMS F381

SOLAR
COLLECTORS
F378

SOLAR HOT
WATER HEATERS
F379

PHOTOVOLTAIC
CELLS
F380

SUB-COMMITTEES

DESIGN CRITERIA

PERFORMANCE

ELECT. GEN. & CON.

SITING/INSTL'N

SAFETY

TECHNICAL COMMITTEES - Responsible for the technical content of standards. Established by Steering Committee, the membership should have a similar balance. Usually includes subcommittee chairmen.

SUB-COMMITTEES - Responsible for providing technical knowledge, ideas, and experience towards development of standards. Should reflect a national consensus of producers, users, regulatory authorities and other interests.

Figure 3

Specifically, the CSA TC WECS shall be responsible for WECS standards development, which will encompass the following:

1. Safety
2. Design Criteria
3. Durability and Reliability
4. Performance and Testing
5. Siting
6. Installation
7. Terminology
8. Certification and Labelling

Standards developed by CSA TC WECS shall address all aspects related to WECS in each of the areas listed under 2.0, including, but not limited to:

a) Required and recommended design criteria

b) Methods of testing of Wind Energy Conversion System Components and Systems

c) Recommended practices

d) Performance Specification

e) Qualification of test facilities

f) Qualification of Wind Energy Conversion Systems Installation and Maintenance Contractors.

g) Qualification of Manufacturers Quality Control Systems and Management.

Figure 4

The Objectives of the Technical Committee on WECS are to:

1. Provide means of measuring performance. (Wind speed vs power output) so that one machine may be compared with another.
2. Provide a means of measuring the amount of wind available at a location so as to insure that sufficient energy will be available for the intended purpose.
3. Provide a method of installation which will be safe.
4. Provide manufacturers with a guide as to the various aspects of aerogenerator design they should concern themselves with throughout its development.
5. Insure that the structure is inherently safe.
6. Provide guidelines of how the electrical connections shall be made to an aerogenerator. In this area interconnection to the grid is of major concern.
7. Insure that the certification agency can adequately perform all the required tests.
8. Provide label information that will be useful to the user and certification authority.
9. Provide a glossary of terms, so as to minimize misunderstanding of the standard's intent.

Figure 5

Small Wind Energy Conversion Systems - Safety Subcommittee

1. Scope

1.1 This Standard is concerned with design, operation and environmental conditions necessary for safe and reliable operation of Wind Turbines.

1.2 This Standard is concerned with systems of 100 kW or less of rated power, mechanical, or electrical.

1.3 This Standard deals with control and protection mechanisms.

1.4 This Standard is concerned with the supporting structure including guys and foundations.

1.5 This Standard is concerned with the components and materials supplied by the manufacturers, with the adequacy of the assembly and installation and instructions, and with the system after assembly according to those instructions.

1.6 This Standard is not concerned with Siting of the Wind Turbine, Power Conditioning Subsystems or Interconnection to the power grid, with wind turbine performance, electromagnetic interference or noise.

1.7 Compliance with this Standard does not relieve any person from the responsibility of observing building, fire and safety regulations of local, provincial, and federal jurisdiction.

1.8 This Standard is not intended as a design specification or an instruction manual for untrained persons.

1.9 Where reference is made to other publications such references shall be considered to refer to the latest edition approved by the organization issuing the publication unless specifically noted otherwise.

Figure 6

Wind Energy Conversion Systems - Performance Subcommittee

1. Scope

1.1 This Standard applies to Wind Energy Conversion Systems capable of generating mechanical or electrical power.

1.2 This Standard specifies the method for determining and reporting performance characterisitics of WECS.

1.3 This Standard is not concerned with noise except as a discrete value.

1.4 This Standard does not address issues of reliability or durability except with specific reference to performance.

1.5 This Standard is not concerned with the siting of WECS.

1.6 This Standard is not concered with electromagnetic interference (EMI) except as a part of warning notices.

COMMERCIALIZATION OF THE 500 KW DARRIEUS VERTICAL AXIS WIND TURBINE

Lawrence Schienbein
DAF Indal Ltd.
Mississauga, Ontario

At present DAF Indal sees two major near term markets for medium to large scale wind turbines:

(1) Wind turbine arrays or wind farms supplying large electrical networks.

(2) Wind turbine assisted diesel generator plants in remote and isolated sites.

The objective of the commercialization program within the company is to establish wind turbines as a large commercial business.

Specific objectives of the design and development group, of which I am a part, are three-fold:

1. To develop the 500 kW machine for the immediate and long term wind farm/hybrid markets. We believe that there is an immediate wind farm market.
2. Develop wind turbine systems to the commercial stage, including hybrid applications.
3. Identify machine sizes and configurations for the long term markets.

There are four areas of current design and development activity within the company:

1. The series 6400 model 500 kW wind turbine. We're producing three machines in our plant now: the first power module is under test. That machine will be delivered to Southern California Edison in January. We plan to begin tests in February, 1984.
2. Wind turbine technology development. Most of the work in this area is associated with a major contract that we have with the NRC to identify optimum Darrieus machine configurations for the long term market. The company has for the last two or three years been implementing advanced structural, aerodynamic and mechanical system design methods. All of these are computer based.

3. The wind/diesel hybrid work involves:

   a) The completion of the Sudbury project, which we call Sudbury I.

   b) In January we will begin work on Sudbury II. Development and testing of a wind/diesel system with wind turbine stand-alone capability.

   c) We are hoping to obtain a contract to develop computer models of wind/diesel systems.

4. The 50 kW demonstration. This really amounts to ongoing support of the eleven 50 kW machines in the field. From these machines we are deriving a wealth of operating and design information.

   The 50 kW machines in the field span three design generations. It is a fairly mature product, although the machine is not being offered for sale on a commercial basis. It is being offered as a demonstration machine. The machine's most vital role, from our point of view, has been to test several important technical innovations which we are now applying to the 500 kW design.

Some of the unique features of the DAF Indal 50 kW wind turbine are:

a) A hydraulic lower bearing. The rotor in effect "floats" on hydraulic fluid. This permits us to operate the machine with constant guy wire tension, a very significant advantage.

b) A combined gearbox/brake system.

c) A centrifugally activated overspeed protection device (hydraulic dump valve).

d) Our control logic which permits the rotor to coast while offline.

e) The power module approach.

Figure 1 is a schematic of the 50 kW power module. This points out many of the features I described previously. The bull gear doubles as the brake disk for the machine. When the machine is brought to a stop, the hydraulic pressure is relieved and the rotor drops down a fraction of an inch. The bull gear then makes contact with the brake pads. Everything is in the vertical plane even the generator and the output shaft. It is a single mesh gearbox with approximately a 15:1 gear ratio.

500 kW VAWT
****

The significant 500 kW VAWT features are:

a) It is geometrically similar to the Magdalen Island 230 kW experimental machine. That is, it has the same swept area and height to diameter ratio.

b) A 1.5 to 1 height to diameter ratio.

c) Single mesh spur gear transmission with two pinions.

d) Hydraulic lower and upper bearings. The hydraulic upper bearing is now the guy tensioning bearing. The bull gear and the rotor float up to a preset position.

e) The bull gear doubles as the brake disc.

f) Twin 350 hp. (approximately 260 kW) 3 phase induction generators.

g) Extruded aluminum blades.

h) Slightly greater blade chord than that of the Magdalen Islands VAWT. 29" compared to 24".

i) A power module approach.

The power module is shop assembled and tested.

A summary of the standard specifications follows:

Rotor height	120 feet
Diameter	80 feet
Blade chord	29 inches, NACA 0015 profile - 15% thick - extruded aluminum
Capture area	595 m^2 (same as the Magdalen Islands VAWT)
Column diameter	5 feet at the centre 3 feet at the ends

The column is tapered away from the centre towards the ends. This gives the advantage of reducing the mass at the top of the rotor, which is significant from a structural dynamic point of view.

The rotor weight is about 20 tons.

The power module weight is about 20 tons

The rated electric output is about 522 kW.

Rated power is reached at 19 m/s (43 mph) measured at the rotor equator.

The rotor speed is 45 rpm (synchronous speed).

Braking torque capacity is 272,000 Newton-m. Braking torque capacity is two times the rated torque output of the machine.

QUESTIONS

Q What happened to the one in Prince Edward Island with the red and white stripes? They were going to put that on a school weren't they?

A It did operate on a school there for some time. That machine was dismantled and is the same machine recommissioned at the Atlantic Wind Test Site.

Q How many units do you have in the field altogether?

A Counting the Magdalen Islands machine, we have 12 units, 50 kW and up. DAF built a number of smaller machines. The 30 x 20 foot machine, such as at Toronto Island, and also a number of 18 foot x 15 foot machines, one of which is on the roof here at Ryerson. Those machines were all built before my time at DAF Indal. I'm not sure where they all are. A 6 m x 9 m (20' x 30') machine is also installed at the Atlantic Wind Test Site.

Q 1. What is the anticipated cost of the 500 kW machine?

2. Could you give us a brief summary of what you think are the advantages of vertical over horizontal axis machines?

A 1. The 50 kW machine has a price of about $150,000. At that price you are not going to attract any commercial interest whatsoever. The 500 kW machine is being offered commercially a a price of $505,000 U.S. (about $600,000 Canadian). So we've gone from a $3000/kW demonstration price to approximately a $1200/kW commercial price. Even at $1200/kW there are many applications where it is not cost effective. But at $1200/kW that machine is already cost competitive in many diesel generator applications. At the moment we think it is competitive for grid connection in some windfarm applications.

2. The very significant advantage from our point of view is in having the gearbox, generators, switchgear, control system and hydraulic system at ground level. The Darrieus rotor offers the easiest approach to hybrid systems. It is a clear winner in pumping applications, wind/diesel applications or any kind of mechanical hook-up. The extra cost for a HAWT yaw system, with the working parts of the machine mounted on the top of the tower, and the variable pitch mechanism do not seem to be compensated for by the value of the energy gained. As Marc Chappell pointed out, if you keep a wind turbine simple, even though you may pay a small penalty in terms of performance, the advantages of simplicity will compensate.

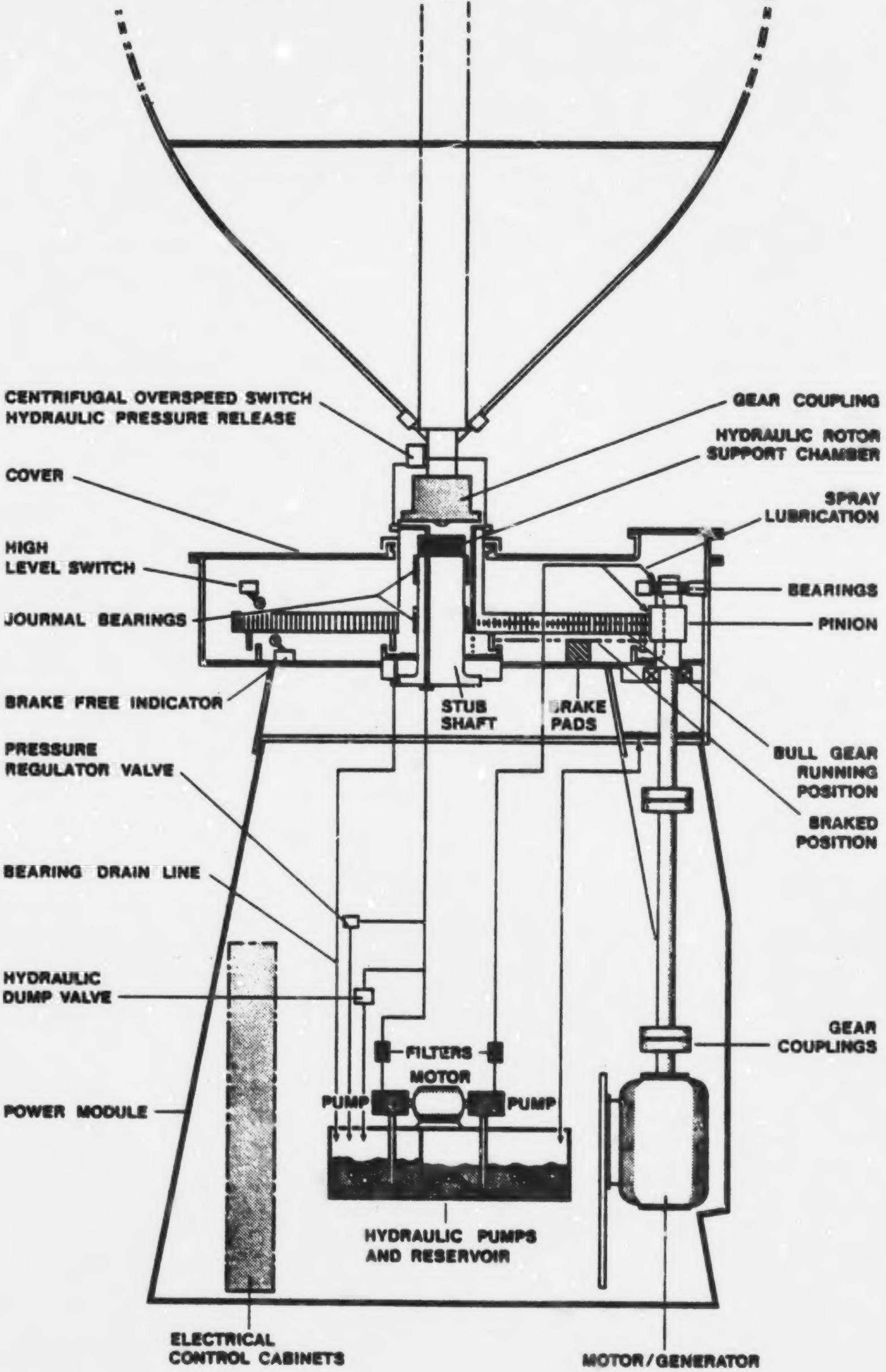
Q Could you please comment on the reliability of a Darrieus rotor as opposed to a straight bladed rotor in a horizontal axis machine?

A If the rotor of our machine is structurally sound in terms of vibratory stress levels and so on, the rotor is the last thing that we will worry about on the device, because it is very simple. If you go to a variable pitch type horizontal axis machine or any kind of horizontal axis machine with good blade design and good root connection design, then you should have no problems either.

Q But why is it your machines seem far more reliable than the majority of the machines in operation in Southern California?

A Eight years of experience. There is no way to short circuit the development process. I'm not an old hand at engineering by any means but I believe that if you look at similar product developments of this scale then you're looking at least at 5 years, in a lot of cases 10 to 12 years, for product development. The only way to speed that up is to be so smart right from the beginning that you bypass a lot of the dead ends. It has been eight years of experience and NRC's initiative to get going with the demonstration program on the 50 kW machines in Canada. Having those machines in the field and getting the feedback of information was absolutely vital.

Figure 1


CENTRIFUGAL OVERSPEED SWITCH
HYDRAULIC PRESSURE RELEASE
GEAR COUPLING
HYDRAULIC ROTOR SUPPORT CHAMBER
COVER
SPRAY LUBRICATION
HIGH LEVEL SWITCH
BEARINGS
JOURNAL BEARINGS
PINION
BRAKE FREE INDICATOR
STUB SHAFT
BRAKE PADS
PRESSURE REGULATOR VALVE
BULL GEAR RUNNING POSITION
BRAKED POSITION
BEARING DRAIN LINE
HYDRAULIC DUMP VALVE
FILTERS
MOTOR
GEAR COUPLINGS
PUMP
PUMP
POWER MODULE
HYDRAULIC PUMPS AND RESERVOIR
ELECTRICAL CONTROL CABINETS
MOTOR/GENERATOR

WIND ENERGY ANALYSIS AT SELECTED SITES IN ONTARIO

Robert Morris,
Atmospheric Environment Service
(edited transcription of oral presentation)

Work Backgrounder:

Bob Morris is a meteorologist who has been with the Atmospheric Environment Service (A.E.S.), Environment Canada, since 1972. He has worked in Air Quality Applications and as a weather forecaster on the east coast, British Columbia and in the Arctic. Presently he works in the Energy Applications and Impacts Unit, Canadian Climate Centre, Downsview, Ontario, building on work that he and Don McKay have been doing for approximately the last 3 years. They have had a computer code developed by the Alberta Research Council and applied to A.E.S. digital wind information, after converting that data into a format suitable for wind energy analysis at different sites.

Presentation:

First of all let me give you a little bit of background. The A.E.S. of Environment Canada has the mandate to provide a baseline of regionally representative climatological information, not details for every nook and cranny in every part of the country. For many years we have provided very general wind information, usually just on windspeed and direction and their basic statistics. This is the first real attempt that we've made at a comprehensive analysis for wind energy use.

The Alberta Research Council performed a wind energy analysis under contract on hourly wind data for the period of 1967 - 1976 for 144 locations nationally. Twenty-four of these are in Ontario. Hourly windspeeds were adjusted to the standard 10 metre height at the few sites where the anemometer was at a non-standard height. This adjustment, along with the standard period of analysis permits an "apples with apples" comparison between statistics at different locations. Hourly wind power and energy were calculated using hourly speeds and hourly, not average, values of air density, temperature and pressure.

In a recent publication, "Wind Energy in the North West Territories", similar analyses were performed using the same software package except that energy values were reduced by the Betz fraction (.59) so that only those wind energy amounts theoretically available for conversion were reported. Our study does not use the Betz coefficient.

The result of this project is a series of tabular and graphical wind energy analyses. Only masters are currently available. However, these data will be published in the near future by Environment Canada entitled "Wind Energy Data Analyses for Canada

1967 - 1976". They will appear in six regional volumes. (publication date - June 1984 - Ed.)

What I'll do is run through some of the tables and graphs that have been produced by this package for publication. The numbers I don't think are too important, it's mainly just the format and its utility that I want to point out here.

Table 1 is for Gore Bay in Ontario. It is one of the moderate windspeed sites. The months of the year are across the top followed by monthly mean air temperature, air pressure and windspeed. Then we have "by month", the wind direction frequency, hours per month and percentage of time. This is a basic wind analysis, not focusing on wind energy.

Table 2 is a joint frequency distribution with mean windspeeds by month and by direction with the average windspeed by direction and the average windspeed for all directions by month. The effective wind speed is defined as the cube root of the average of the cubes of the wind speed. It graphically shows that you can't cube average windspeeds because it is not algebraically correct and results in a conservative estimate of wind energy.

Table 3 is a joint frequency distribution showing the mean directed wind power in watts/m^2 by direction. This is better shown on one of the graphs obtained, i.e. Gore Bay - [Figure 1] Total Annual Directed Recorded Wind Energy. It shows that most of the energy comes from the West-North-West around through to South winds. If you are siting a wind generator at this location, that sector is the one that you must be most careful concerning obstructions up-wind. Of course, this will vary from site to site. Gore Bay is on the north shore of Manitoulin Island.

Q Wouldn't it by more appropriate to express it by compass direction as a % of annual total rather than to actually plot a specific value? Would it be just as useful to give a percent of total and then just give the total annual energy from all directions for that site? You could then obtain the total amount of energy from that compass direction for that site on average, by multiplying the total annual energy by that compass direction's average percentage of total.

A That would be useful, too. This graph displays the total energy, too. An example of usefulness of this graph would be Atikokan, which is one of the least windy sites. It might show the same normalized pattern as Cape St. James off the B.C. coast. You may not get the impression of how much different the wind energy is whereas in a graph like this, you would.

Q I take it from the data down below that the site you are looking at is a 1.1 MW-h/m^2 or 4,500 MJ/m^2 multiplied by roughly 1/4 to get a 250 kW-h/m^2. It's a rather useful number.

A Yes. Or the other way, it comes out to approximately 140 W/m^2 for this particular site, if you apply the right multiplier. It can be expressed in any unit you wish.

Table 4 displays the joint frequency distribution that appeared in Figure 1. This is expressed in recorded energy by direction whereas the previous is mean power by direction.

Table 5 is the actual Recorded Wind Energy by Year for the 10 year period. Note the minimum and maximum. The minimum yearly recorded energy is 2635 MJ/m^2 and the maximum is almost 5600 MJ/m^2. So there is more than a 100% difference just in 10 years between the minimum recorded energy in a year and the maximum in a year. These statistics have been generated for each site. That is one thing which may be important to look at for applying a wind generator to an end-use.

Figure 2 presents the diurnal variations or mean hourly average windspeed by hour during the day. The hour is the x-axis and month is across the top. This is hourly mean windpower in watts/m^2. The top graph presents the winter months: January, February and March. In March, once the sun starts to shine rather brightly, there is strong heating which is shown in this peak at the time of maximum heating. On the other hand, January has very little heating during mid-day. Consequently, it is one of the flattest curves although one the windiest months. It shows very little diurnal variation in the energy. The other point is that January, February and March are all above the annual curve, whereas July, August and September are all below the annual curve although they all show the diurnal variation. There is not a lot of variation in the shape of the curves from site to site though the absolute values differ. However, there may be places in the Arctic where the heating at mid-day is never that strong.

Table 6 is entitled the Wind Energy Profile, and is one of the more useful and interesting formats. We have speeds incremented by 5 km/h on the left hand side and the fraction of time when the windspeeds are greater than the indicated windspeeds by month across the top. Also, the total energy in the winds having speed greater than this windspeed and the fraction of monthly total wind energy this represents is presented.

These data may have greater utility when presented as a graph, such as in Figure 3, which shows a plot of the annual wind energy profile. It displays the percentage of time when, on the left hand axis, wind power exceeds a specified value, or on the right hand axis, the wind speed exceeds a specified value. Selected values of total energy in winds exceeding a specified value are plotted along the curve. An example of use of this graph follows for a wind turbine with, say, cut-in speed of 16 km/hr. and cut-off speed of 42 km/hr. From the graph the available wind energy on a mean annual basis in the operating range of this machine is the difference between 4101 and 666 MJ/m^2, or 3435 MJ/m^2.

Table 7 is a frequency of duration events analysis, another useful table, especially for designing storage facilities. This is for the condition of windspeed less than or equal to 15 kph.

- 'x' is the duration of the period in hours
- 'n' is the number of periods in this ten year overall period that lasted 'x' hours or more

and

- 'f' is the number of periods that lasted exactly 'x' hours

These tables have been produced for the following threshold windspeeds: less than or equal to 15, 20, 25, 30, 35 km/h and greater than 15, 20, 25, 30, 35 and 100 kph. One of the most useful of these is the "less than or equal to 15 km/h" table since 15 km/h represents the range of commonly occurring cut-in windspeeds for wind turbines. In fact, this is the one table of the group that is also presented graphically.

From Figure 4, where this information is plotted, we can see that once every five years a duration of 95 hours, during which the windspeed never exceeds 15 km/h, can be expected. An obvious extension of this application is fitting a line to the data on the graph and extrapolating to longer periods, say 50 years.

Table 8 shows Weibull parameters that have been estimated for some Ontario locations. The hybrid Weibull distribution, after Takle and Brown, 1978 has been adopted. The hybrid Weibull distribution is the standard Weibull distribution with an allowance made for the occurrance of calm winds which may be artificially high due to high threshold values of anemometers. In practical terms, calm windspeeds are removed from the windspeed distribution, Weibull parameters are fitted by the least squares method to the resulting distribution, and the percentage of calms introduced to normalize the equations when the hybrid Weibull distribution is used to calculate distribution statistics such as the mean, etc. These parameters have been calculated for each of the 144 locations. Note that these Weibull parameters must be used with the percentage of calm winds and the hybrid distribution.

The equations for the probability and cumulative density functions are available in Takle and Brown, 1978.

A common practice is to use a Rayleigh distribution for windspeed (set the Weibull shape factor to 2) and we can see from Table 8 that the shape factors in Ontario are not very different from 2, at least on an annual basis. However, this varies geographically and many areas of the country show shape factors on average closer to 1.5. The reasons for these regional differences are not well understood.

A further initiative with regard to these wind energy data was to prepare national wind energy maps for Canada. Working maps with plotted values were sent to AES regional offices. AES meteorologists in each region provided contour analyses of wind speed and energy, for their respective regions, by month and annually, which are being currently integrated into national analyses. A draft of this national map appears in Figure 5. Units are GJ/m^2/yr. In the national context, Ontario is not a very windy province. Except for Sudbury, (5.8 GJ/m^2/yr), the only locations showing energy densities greater than 5 GJ/m^2/yr are the exposed coasts of the Great Lakes and Hudson/James Bay. In fact, some locations deep in the boreal forest such as White River and Atikokan are some of the least windy sites in the country. Energy densities greater than 10 GJ/m^2/yr are common over the barren lands of the Northwest Territories and greater than 20 GJ/m^2/yr over the Pacific and Atlantic outer coasts. Some individual sites include 34 GJ/m^2/yr at Cape St. James on the B.C. coast and 23 GJ/m^2/yr at the Magdelen Islands in the Gulf of St. Lawrence. It is important to realize that wind energy densities analysed on this map are representative of typical airport anemometer sites. The sites, in small scale, are relatively exposed, that is free from nearby obstructions such as buildings and vegetation. However, like airport sites, they are often sheltered in the broader scale by being located in mountain valleys and away from exposed coasts. Care must be exercised in using data from this map or these analyses when comparing to any specific site and exposure.

Q Is that taking into account the effect of anemometer height at Cape St. James?

A No, it isn't. It's a 200 m high pile of rocks in the middle of the ocean. In effect a very tall anemometer mast. Plus the dynamic effects of the presence of the headland too. The Magdalen Islands has a similar type of problem because the anemometer happens to be on a low, smooth isolated hill which causes terrain speed-up. When you see wind data, look at it very critically. If you are not quite sure what to look at then talk to an AES meteorologist because it can be misleading. There are lots of different things to consider when looking at wind information.

Q How are these values measured?

A On a U2A and 45B. These I think are U2A's because all this wind data in the archives had all the temperatures and pressures. Therefore they are almost all from airports which are U2A anemometers. The hourly wind is not an hourly wind run but a one minute mean every hour. Over the long term it is representative of the hourly windspeed. It is a rotating cup anemometer.

Q In your talk there I noticed you were talking kph then m/s is there any standard for those?

A Well. A.E.S. officially reports wind in kph for public use. For scientific use it is m/s that is de facto. So these charts will be done in kph. The energy units are MJ/m^2 or GJ/m^2 simple conversion to kW-h or mean power $watts/m^2$.

I would like to point out other sources of wind information. Volume 5 of the Canadian Climate Normals contains analyses of windspeed and direction for almost 500 locations in Canada. The information they provide includes:

- percent frequency of direction by month
- average windspeed by month and by direction
- the mean windspeed for all directions annually
- the maximum recorded hourly speeds and gusts if they have been extracted (that can be very useful) and.
- a description on the siting of the anemometer down below.

It is just not sufficiently comprehensive for wind energy purposes. They can be ordered from AES.

I'd like to also mention that the wind and other climate information is in the digital archive at AES Downsview and available on magnetic tape at reasonable cost.

Q You are looking at data that goes back roughly 10 years or more and yet there is a comment that the weather patterns are changing in the next few years/decades. They are going to go back more to what the periods were prior to the War where there was very much greater change in the weather over shorter periods of time. Will that effect the wind or do you have information back in that period when the weather was changing very rapidly?

A Yes, we have records that we could look at but we haven't looked at them. As a general rule the colder and more wintery the weather in the winter, the windier it is.

Q We are going to get higher wind patterns in the next little while?

A I can't definitively answer your question. Maybe we should do that study. The question is well worth answering, I think.

REFERENCES

1. Wind Energy in the Northwest Territories. B. Janz, D.G. Howell and A. Serna, 1982.
2. Canadian Climate Normals (1951-80), Volume 5. Wind, Atmospheric Environment Service.
3. Note on the Use of Weibull Statistics to Characterize Wind Speed Data, Journal of Applied Meteorology, Volume 17, No. 4, April 1978.

TABLE 1

GORE BAY A, ONT
WIND SUMMARY
ANALYSIS PERIOD: JAN 1967, TO DEC 1976

LATITUDE: 45°53'N
LONGITUDE: 82°34'W
ELEVATION: 193 m

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
MEAN AIR TEMPERATURE (°C)	-9.0	-9.4	-4.1	3.4	9.7	15.6	18.7	18.6	14.1	8.8	1.8	-5.3	5.2
MEAN AIR PRESSURE (kPa)	99.14	99.13	99.12	99.16	99.07	98.99	99.10	99.27	99.32	99.32	99.03	99.20	99.15
MEAN WIND SPEED (km/h)	18.5	17.3	17.9	17.4	15.4	14.0	14.6	14.8	16.0	18.6	19.4	19.2	16.9
WIND DIRECTION FREQUENCY (hours/month)													
N	42	55	49	57	43	30	29	31	32	37	50	62	516
NNE	28	53	43	45	44	29	22	26	23	21	34	32	403
NE	38	51	46	49	43	32	25	37	29	34	47	49	479
ENE	53	43	38	30	27	23	12	28	21	38	49	70	433
E	74	44	52	31	34	27	15	25	29	45	53	84	514
ESE	34	20	34	24	27	22	12	16	34	34	32	40	329
SE	19	12	22	22	23	31	18	20	28	31	21	24	273
SSE	15	14	30	34	45	59	41	30	44	52	23	15	402
S	32	34	53	62	77	116	109	83	77	104	44	39	829
SSW	46	29	31	35	38	53	63	65	49	46	29	36	521
SW	37	21	27	32	38	47	55	69	44	36	37	32	474
WSW	33	22	21	27	32	33	43	44	32	37	39	32	395
W	92	52	63	64	73	69	100	91	75	75	88	59	901
WNW	54	63	77	71	65	46	82	70	72	51	48	40	741
NW	43	51	53	41	37	23	41	37	49	36	56	40	508
NNW	46	47	40	38	26	13	19	19	32	33	37	47	397
CALM	56	67	66	56	72	68	57	53	49	33	30	44	650
WIND DIRECTION FREQUENCY (% of time)													
N	5.6	8.1	6.6	7.9	5.8	4.1	3.9	4.2	4.4	4.9	7.0	8.3	5.9
NNE	3.8	7.8	5.8	6.3	6.0	4.1	3.0	3.5	3.3	2.9	4.7	4.3	4.6
NE	5.1	7.5	6.2	6.7	5.7	4.4	3.3	4.9	4.1	4.5	6.5	6.6	5.5
ENE	7.2	6.4	5.1	4.2	3.6	3.1	1.6	3.7	3.0	5.1	6.9	9.4	4.9
E	10.0	6.5	7.0	4.3	4.6	3.7	2.1	3.3	4.0	6.0	7.4	11.3	5.9
ESE	4.6	3.0	4.5	3.4	3.6	3.1	1.6	2.1	4.7	4.6	4.5	5.4	3.8
SE	2.6	1.8	2.9	3.1	3.1	4.3	2.5	2.6	3.9	4.2	3.0	3.2	3.1
SSE	2.1	2.1	4.1	4.7	6.0	8.2	5.5	4.1	6.1	6.9	3.3	2.1	4.6
S	4.3	5.0	7.1	8.6	10.4	16.1	14.7	11.1	10.7	14.0	6.1	5.2	9.5
SSW	6.2	4.3	4.1	4.9	5.1	7.4	8.4	8.8	6.9	6.2	4.1	4.8	5.9
SW	5.0	3.1	3.7	4.5	5.1	6.5	7.3	9.2	6.2	4.8	5.2	4.3	5.4
WSW	4.4	3.3	2.8	3.7	4.4	4.6	5.8	5.9	4.4	5.0	5.5	4.3	4.5
W	12.4	7.7	8.4	8.9	9.8	9.6	13.4	12.2	10.4	10.1	12.2	8.0	10.3
WNW	7.3	9.3	10.3	9.8	8.8	6.5	11.1	9.5	10.0	6.9	6.6	5.4	8.5
NW	5.8	7.5	7.1	5.8	4.9	3.2	5.6	4.9	6.8	4.8	7.8	5.4	5.8
NNW	6.2	7.0	5.4	5.3	3.4	1.8	2.6	2.6	4.5	4.4	5.1	6.3	4.5
CALM	7.5	9.9	8.8	7.8	9.6	9.5	7.6	7.1	6.8	4.5	4.2	5.9	7.4

TABLE 2

GORE BAY A, ONT
WIND SUMMARY
ANALYSIS PERIOD: JAN 1967, TO DEC 1976

LATITUDE: 45°53'N
LONGITUDE: 82°34'W
ELEVATION: 193 m

MEAN WIND VELOCITY (km/h)

DIRECTION:		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
	N	16.1	17.3	18.8	18.2	14.1	14.6	13.8	14.5	15.4	17.8	19.7	20.0	17.1
	NNE	15.3	16.4	17.5	15.9	13.3	15.3	13.7	14.8	16.9	17.7	20.4	20.8	16.5
	NE	17.1	17.2	20.0	18.3	15.3	15.2	14.9	15.3	16.7	18.9	21.2	22.3	18.0
	ENE	19.2	17.8	21.8	20.4	15.5	14.3	12.1	15.5	16.4	17.6	20.9	20.8	18.6
	E	18.1	18.3	20.1	19.7	17.7	12.5	10.2	12.0	10.8	14.1	16.1	18.4	16.7
	ESE	16.3	17.4	19.7	20.7	20.0	13.4	9.0	10.1	12.5	13.6	15.2	16.7	15.9
	SE	17.2	15.0	16.1	15.4	15.7	14.7	11.3	11.8	14.4	15.5	14.7	15.5	14.8
	SSE	18.1	16.2	19.2	17.6	16.3	16.0	13.7	15.0	16.3	18.9	18.1	17.6	16.8
	S	22.8	23.5	20.1	19.8	18.0	16.5	16.9	17.6	19.1	22.7	22.1	21.1	19.3
	SSW	28.8	25.9	20.6	18.7	15.8	14.9	16.4	18.0	20.2	22.1	23.0	23.7	20.2
	SW	26.9	21.0	20.2	18.2	15.8	15.0	15.6	16.5	18.5	20.9	22.6	21.2	18.8
	WSW	24.0	20.2	18.1	18.0	16.3	14.6	15.3	15.7	18.8	22.1	22.6	21.9	19.9
	W	21.7	20.2	19.2	18.0	18.7	16.4	17.3	16.5	19.0	21.5	22.0	23.7	19.4
	WNW	19.7	20.5	21.2	21.1	22.0	18.6	19.3	18.1	19.3	21.8	22.0	21.5	20.3
	NW	17.7	18.9	18.9	19.2	17.8	14.3	16.3	14.6	15.4	18.7	19.8	20.4	17.9
	NNW	17.5	21.2	20.0	20.3	15.6	11.4	13.4	13.4	15.2	17.3	18.8	19.3	17.9
MEAN WIND SPEED FROM ALL DIRECTIONS	(km/h)	18.5	17.3	17.9	17.4	15.4	14.0	14.6	14.8	16.0	18.6	19.4	19.2	16.9
EFFECTIVE MEAN WIND SPEED**	(km/h)	24.4	23.6	23.3	22.5	20.3	18.2	18.8	18.7	20.4	23.0	23.9	24.4	22.0

TABLE 3

MEAN DIRECTED WIND POWER (W/m²)

DIRECTION:		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
	N	101.7	132.0	152.4	134.2	67.1	64.6	60.7	69.6	87.9	120.1	166.9	170.4	119.0
	NNE	96.5	118.4	144.3	97.4	55.7	85.7	57.6	71.8	95.7	130.2	171.4	202.1	112.1
	NE	130.2	139.5	224.9	145.6	93.2	78.0	77.1	77.7	99.6	151.0	199.7	281.5	150.2
	ENE	181.9	165.7	255.3	211.6	93.3	69.4	39.7	88.8	108.1	124.2	193.2	211.1	164.6
	E	154.1	159.6	167.7	188.1	126.5	51.9	34.2	47.5	35.8	70.5	96.5	154.8	122.3
	ESE	116.4	153.8	182.3	210.6	185.6	65.0	17.0	23.5	48.3	60.5	89.5	113.2	110.9
	SE	139.0	101.7	128.0	96.2	87.5	88.2	35.7	40.6	62.4	86.7	83.8	99.2	87.1
	SSE	167.5	123.7	185.8	122.4	95.3	96.8	60.2	71.0	96.4	135.5	172.1	142.1	114.6
	S	280.1	312.6	203.2	188.7	124.8	97.3	103.2	113.3	154.0	232.3	243.3	200.0	166.4
	SSW	493.0	386.4	210.2	167.2	94.4	71.1	91.3	109.5	171.0	208.7	276.7	296.9	198.5
	SW	419.5	243.2	221.2	165.6	83.4	70.4	73.0	84.4	126.0	207.9	240.3	222.5	162.9
	WSW	368.4	288.5	170.8	184.1	103.2	66.9	75.3	78.7	132.6	242.9	259.7	258.4	179.6
	W	243.7	232.9	192.4	147.5	151.3	97.8	108.8	97.6	146.0	214.6	239.8	341.9	179.8
	WNW	221.7	216.2	218.5	203.6	230.7	133.7	148.1	129.3	158.6	227.5	235.2	255.2	194.4
	NW	165.0	207.4	164.5	183.1	146.0	64.9	110.5	76.0	80.9	152.2	166.1	220.1	149.4
	NNW	140.5	278.5	197.0	180.1	95.9	35.0	51.8	57.5	90.4	111.8	151.5	177.0	150.7
MEAN WIND POWER FROM ALL DIRECTIONS	(W/m²)	201.3	186.6	173.8	151.4	109.0	76.6	83.6	82.8	108.7	160.3	183.6	200.1	142.7

** The EFFECTIVE MEAN WIND SPEED is the cube root of the mean cubed wind speed.

TABLE 4

GORE BAY A, ONT
WIND SUMMARY
ANALYSIS PERIOD: JAN 1967, TO DEC 1976

LATITUDE: 45°53'N
LONGITUDE: 82°34'W
ELEVATION: 193 m

MEAN DIRECTED WIND ENERGY (MJ/m²) (MJ x 0.28 = kWh)

DIRECTION:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
N	15.3	25.9	26.9	27.5	10.5	6.9	6.4	7.9	10.0	15.8	30.3	37.8	221.2
NNE	9.8	22.5	22.3	16.0	8.9	9.0	4.6	6.8	8.1	10.1	21.0	23.4	162.4
NE	17.7	25.4	37.5	25.5	14.3	9.0	6.9	10.3	10.6	18.3	33.8	49.6	258.8
ENE	34.8	25.7	34.6	22.8	9.0	5.6	1.7	8.9	8.4	17.1	34.4	53.4	256.4
E	41.3	25.3	31.3	21.1	15.7	5.0	1.9	4.3	3.7	11.4	18.6	46.9	226.2
ESE	14.5	11.1	22.2	18.5	18.1	5.2	0.7	1.3	5.9	7.4	10.4	16.3	131.5
SE	9.8	4.5	10.1	7.8	7.4	9.9	2.4	2.9	6.3	9.8	6.5	8.4	85.6
SSE	9.3	6.4	20.3	14.8	15.3	20.5	8.8	7.7	15.2	25.2	14.6	7.9	165.9
S	32.0	38.1	38.8	42.1	34.8	40.5	40.6	33.8	42.5	87.2	38.2	27.9	496.6
SSW	81.8	40.7	23.2	21.1	12.9	13.6	20.6	25.7	30.4	34.9	29.3	38.2	372.4
SW	56.2	18.2	21.7	19.1	11.3	11.8	14.3	20.9	20.2	26.7	32.2	25.6	278.2
WSW	43.8	22.9	12.7	17.9	12.1	7.9	11.6	12.5	15.3	32.5	36.9	29.5	255.6
W	80.7	43.6	43.5	34.2	39.5	24.3	39.1	32.0	39.3	58.1	75.9	72.9	583.1
WNW	43.4	49.2	60.4	52.0	54.1	22.4	44.0	32.8	41.3	42.0	40.5	36.7	518.8
NW	25.7	37.9	31.3	27.4	19.3	5.4	16.5	10.0	14.2	19.7	33.7	31.9	273.0
NNW	23.2	47.4	28.7	24.8	8.8	1.6	3.6	4.0	10.5	13.1	20.0	29.7	215.5
MEAN WIND ENERGY FROM ALL DIRECTIONS (MJ/m²)	539.2	444.8	465.4	392.4	292.0	198.6	223.8	221.8	281.8	429.4	476.0	536.0	4501.4

TABLE 5

RECORDED WIND ENERGY (MJ/m²) (MJ x 0.28 = kWh)

YEAR:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1967	721.5	658.2	513.5	522.4	439.6	192.2	267.1	272.5	287.1	586.3	473.9	661.2	5595.4
1968	447.8	738.8	447.5	529.7	216.9	181.3	260.9	162.7	170.6	314.8	389.3	547.2	4407.7
1969	273.9	165.6	218.2	186.5	183.8	255.3	113.5	188.6	202.5	311.3	239.6	296.3	2635.2
1970	135.6	354.2	368.0	406.5	303.0	168.3	153.7	200.5	272.1	267.2	576.9	669.3	3875.3
1971	573.3	761.8	460.9	314.1	321.8	121.2	311.3	233.8	252.7	406.2	545.3	677.4	4979.9
1972	817.6	261.6	400.3	194.4	109.7	144.3	123.8	125.7	226.4	601.5	406.2	513.1	3924.7
1973	518.3	312.2	501.2	584.6	396.5	211.1	248.3	221.8	353.6	437.9	640.7	617.7	5044.0
1974	545.8	324.8	598.6	378.4	475.4	316.2	257.4	298.6	426.1	411.2	386.8	351.7	4772.0
1975	744.6	309.0	371.9	390.4	147.5	206.5	249.6	283.3	270.9	500.4	588.0	413.4	4475.5
1976	613.8	569.9	772.3	417.3	325.9	189.6	252.2	230.2	355.7	457.2	512.9	612.9	5309.8
MEAN OF RECORDED ENERGY (MJ/m²)	539.2	444.8	465.4	392.4	292.0	198.6	223.8	221.8	281.8	429.4	476.0	536.0	4501.4
STANDARD DEVIATION OF RECORDED ENERGY (MJ/m²)	211.3	215.6	149.0	133.9	124.7	55.3	67.6	54.5	77.6	112.7	121.2	138.7	860.5

TABLE 6

GORE BAY A, ONT
WIND SUMMARY
ANALYSIS PERIOD: JAN 1967, TO DEC 1976

LATITUDE: 45°53'N
LONGITUDE: 82°34'W
ELEVATION: 193 m

WIND ENERGY PROFILE

%t: FRACTION OF TIME WHEN WIND SPEEDS ARE GREATER THAN v (%)
pe: TOTAL ENERGY IN WINDS HAVING A SPEED GREATER THAN v (MJ/m²) (MJ x 0.28 = kWh)
%e: FRACTION OF MONTHLY TOTAL WIND ENERGY REPRESENTED BY pe (%)

v: (km/h)		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
5	%t	87.9	84.1	86.5	87.7	84.7	84.4	87.0	88.1	89.0	92.0	92.2	90.6	87.9
	pe	539.1	444.7	465.2	392.3	291.9	198.4	223.6	221.6	281.6	429.3	475.9	535.9	4499.5
	%e	100.0	100.0	100.0	100.0	99.9	99.9	99.9	99.9	93.9	100.0	100.0	100.0	100.0
10	%t	73.1	67.6	72.1	72.0	66.4	62.1	65.7	66.3	69.9	77.8	78.4	77.1	70.7
	pe	535.7	441.3	461.8	388.8	287.8	193.7	219.1	216.9	277.6	426.1	472.8	532.7	4454.3
	%e	89.3	99.2	99.2	99.1	98.5	97.5	97.9	97.8	98.5	99.2	99.3	99.4	99.0
15	%t	58.4	54.3	58.5	56.3	48.8	43.5	45.3	45.9	51.6	61.4	64.7	63.1	54.3
	pe	524.3	431.8	451.4	377.5	275.3	180.9	204.7	202.4	264.8	413.8	462.7	521.9	4311.5
	%e	97.2	97.1	97.0	96.2	94.3	91.1	91.5	91.3	94.0	96.4	97.2	97.4	95.8
20	%t	41.8	38.8	40.5	37.6	30.1	22.8	24.8	25.5	30.2	41.3	45.9	45.1	35.4
	pe	490.5	402.3	415.2	342.0	239.3	143.8	166.9	164.8	225.4	374.6	425.9	485.2	3876.1
	%e	91.0	90.4	89.2	87.1	81.9	72.4	74.6	74.3	80.0	87.2	89.5	30.5	86.1
25	%t	27.9	25.1	25.7	22.7	16.4	10.4	12.0	12.1	15.9	25.0	28.4	28.7	20.9
	pe	427.1	344.9	348.4	278.2	180.2	94.0	114.7	109.9	166.0	303.7	351.0	410.0	3128.0
	%e	79.2	77.5	74.9	70.9	61.7	47.3	51.3	49.5	58.9	70.7	73.7	76.5	69.5
30	%t	14.9	13.0	12.8	10.6	6.4	3.2	3.8	3.8	5.9	11.6	13.3	13.9	9.4
	pe	328.1	260.1	252.1	191.0	109.0	45.3	58.5	52.4	99.5	207.1	241.1	297.7	2141.9
	%e	60.8	58.5	54.2	48.7	37.3	22.8	26.1	23.6	35.3	48.2	50.7	55.5	47.6
35	%t	7.0	5.6	5.8	3.9	2.2	0.8	1.2	0.8	2.3	4.8	5.4	6.1	3.8
	pe	223.5	170.8	161.1	109.2	56.7	17.5	27.4	17.1	56.3	122.0	142.4	195.6	1299.7
	%e	41.5	38.4	34.6	27.8	19.4	8.8	12.3	7.7	20.0	28.4	29.9	36.5	28.9
40	%t	3.4	2.7	2.3	1.7	0.9	0.2	0.3	0.2	0.9	1.7	1.9	3.0	1.6
	pe	147.5	113.0	87.3	66.1	30.8	5.2	11.5	5.0	29.7	58.3	73.0	128.7	756.1
	%e	27.4	25.4	18.8	16.8	10.6	2.6	5.2	2.2	10.5	13.6	15.3	24.0	16.8
45	%t	1.7	1.9	1.3	0.8	0.4	0.1	0.2	0.1	0.3	0.7	1.0	1.6	0.8
	pe	94.8	92.3	59.8	40.0	16.9	2.6	6.4	2.4	13.4	30.1	46.8	86.1	491.6
	%e	17.6	20.8	12.8	10.2	5.8	1.3	2.9	1.1	4.8	7.0	9.8	16.1	10.9
50	%t	0.8	0.9	0.4	0.3	0.1		0.0	0.0	0.1	0.2	0.3	0.9	0.3
	pe	58.2	56.6	23.1	20.8	5.5		2.0	0.0	5.4	10.6	20.9	58.7	263.2
	%e	10.8	12.7	5.0	5.3	1.9		0.9	0.0	1.9	2.5	4.4	10.9	5.8
55	%t	0.4	0.5	0.1	0.2	0.0				0.1	0.1	0.2	0.5	0.2
	pe	36.3	33.7	9.5	16.2	0.8				4.2	5.3	12.5	37.4	156.7
	%e	6.7	7.6	2.0	4.1	0.3				1.5	1.2	2.6	7.0	3.5
60	%t	0.2	0.1	0.0	0.1					0.0	0.0	0.1	0.1	0.1
	pe	22.1	12.3	0.0	6.6					0.0	1.2	7.5	13.0	62.7
	%e	4.1	2.8	0.0	1.7					0.0	0.3	1.6	2.4	1.4

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
65	%t	0.1	0.0		0.0							0.0	0.0	0.0
	pe	14.8	5.3		3.1							1.7	0.0	24.9
	%e	2.8	1.2		0.8							0.4	0.0	0.6
70	%t	0.1												0.0
	pe	10.3												17.3
	%e	1.9												0.4
75	%t	0.0												0.0
	pe	4.9												4.9
	%e	0.9												0.1
TOTAL WIND ENERGY (MJ/m²)		539.2	444.8	465.4	392.4	292.0	198.6	223.8	221.8	281.8	429.4	476.0	536.0	4501.4

TABLE 6 (cont)

TABLE 7

GORE BAY A, ONT
WIND SUMMARY
ANALYSIS PERIOD: JAN 1967, TO DEC 1976

LATITUDE: 45°53'N
LONGITUDE: 82°34'W
ELEVATION: 193 m

DURATION AND FREQUENCY OF PERIODS OF WIND SPEED ≤ 15 km/h, THROUGHOUT THE ANALYSIS PERIOD

x: DURATION OF PERIOD (hours)
n: NUMBER OF PERIODS THAT LASTED x HOURS OR MORE
f: NUMBER OF PERIODS THAT LASTED x HOURS

x	n	f	x	n	f	x	n	f	x	n	f	x	n	f
1	7111	2623	15	766	95	29	133	9	42	58	7	58	13	1
2	4488	1058	16	671	97	30	124	13	43	51	6	62	12	1
3	3430	581	17	574	89	31	111	8	44	45	5	64	11	1
4	2849	396	18	485	69	32	103	3	45	40	9	67	10	1
5	2453	291	19	416	67	33	100	5	46	31	1	68	9	1
6	2162	227	20	349	51	34	95	7	47	30	1	69	8	1
7	1935	185	21	298	35	35	88	3	48	29	3	71	7	1
8	1750	194	22	263	25	36	85	1	49	26	2	72	6	1
9	1556	202	23	238	26	37	84	9	53	24	2	73	5	1
10	1354	149	24	212	24	38	75	6	54	22	3	76	4	1
11	1205	124	25	188	14	39	69	4	55	19	2	85	3	1
12	1081	112	26	174	16	40	65	3	56	17	3	94	2	1
13	969	103	27	158	14	41	62	4	57	14	1	108	1	1
14	866	100	28	144	11									

The wind speed was continuously ≤ 15 km/h, for an average of 711 periods per year, or 4004 hours per year.

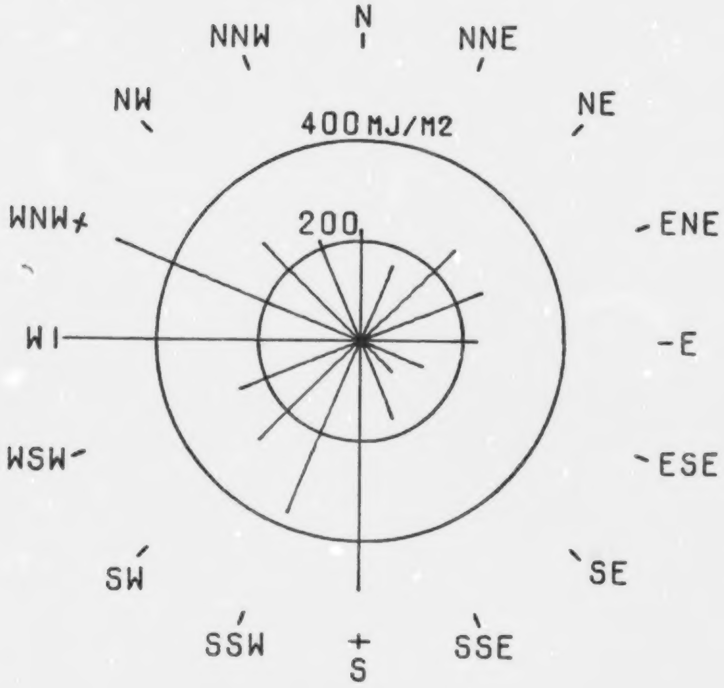
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
TOTAL DURATION OF PERIODS (% of time)	41	45	41	43	51	56	54	54	48	38	35	36	45

TABLE 8

WEIBULL PARAMETERS

C : SCALE FACTOR (km/h)
K : SHAPE FACTOR (dimensionless)
FO: PROBABILITY OF OBSERVING A ZERO WIND SPEED (%)

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
GORE BAY A, ONT	C	23.25	21.98	22.31	21.80	19.77	18.21	18.60	18.56	20.46	22.40	23.48	23.90	21.60
	K	1.98	1.87	2.12	2.04	2.15	2.16	2.21	2.36	2.26	2.26	2.21	2.16	2.05
	FO	7.47	9.89	8.84	7.82	9.64	9.47	7.62	7.08	6.79	4.46	4.19	5.89	7.43
KAPUSKASING A, ONT	C	15.62	15.99	16.44	17.03	15.62	15.23	14.59	14.20	15.33	17.14	16.28	15.35	15.83
	K	1.96	2.02	2.22	2.16	2.20	2.08	2.07	2.15	2.10	2.11	2.08	2.04	2.06
	FO	5.74	8.86	6.10	5.20	7.27	8.08	7.97	9.03	6.96	4.53	6.79	8.70	7.10
KENORA A, ONT	C	17.29	17.24	17.22	17.84	18.52	17.82	17.85	16.85	18.25	18.65	17.96	17.47	17.81
	K	2.32	2.20	2.24	2.25	2.36	2.19	2.19	2.11	2.25	2.13	2.13	2.27	2.19
	FO	6.21	7.01	5.59	3.46	2.25	3.13	2.82	3.70	3.50	4.49	7.42	7.02	4.72
LONDON A, ONT	C	21.54	21.39	20.98	20.65	18.23	16.66	14.37	13.71	14.78	17.07	19.32	20.06	18.52
	K	2.11	2.11	2.07	2.05	2.07	1.87	2.07	2.02	2.05	2.10	2.05	2.08	1.94
	FO	3.36	3.33	4.22	4.36	5.47	7.49	10.67	12.14	8.65	6.18	3.43	3.79	6.09
MOUNT FOREST, ONT	C	21.56	21.13	20.74	20.33	17.73	15.42	14.19	13.24	13.93	16.26	17.75	20.05	18.02
	K	2.20	2.21	2.13	2.02	2.16	2.11	2.12	2.08	1.96	1.97	2.06	2.15	1.95
	FO	5.08	7.80	9.52	9.82	11.13	14.95	20.55	20.23	14.71	8.87	7.72	7.14	11.46
MUSKOKA A, ONT	C	17.01	16.76	17.37	17.21	15.02	14.09	12.70	12.60	13.94	15.95	16.55	16.87	15.72
	K	2.26	2.26	2.35	2.30	2.36	2.23	2.29	2.26	2.46	2.25	2.30	2.21	2.18
	FO	2.28	2.36	2.20	2.47	3.45	4.89	5.32	5.77	6.53	2.61	3.49	3.27	3.72
NORTH BAY A, ONT	C	17.34	17.30	18.53	18.36	16.33	15.32	14.13	13.67	13.97	15.46	16.64	17.03	16.38
	K	2.01	2.01	2.04	2.17	2.26	2.05	2.23	2.18	2.07	2.00	2.04	2.02	2.00
	FO	4.96	5.39	4.13	4.36	5.75	7.28	6.06	7.00	6.46	4.60	5.00	6.61	5.63
OTTAWA INTERNATIONAL A, ONT	C	20.65	20.87	21.82	21.56	17.75	15.47	14.18	14.45	15.40	16.93	18.12	19.57	18.41
	K	2.02	2.12	2.13	2.20	2.16	2.08	2.07	2.00	2.11	2.15	2.09	1.91	1.93
	FO	4.30	4.15	2.88	3.20	5.69	6.70	9.19	8.93	6.56	5.70	5.29	4.62	5.60
SAULT STE MARIE A, ONT	C	20.68	19.06	19.80	19.65	19.34	16.27	17.20	17.10	18.19	20.07	20.96	19.82	19.32
	K	1.83	1.85	1.98	2.06	2.06	2.19	1.95	1.96	1.94	1.94	1.83	1.93	1.86
	FO	9.52	15.24	11.79	10.44	10.65	12.08	14.99	16.77	14.04	10.09	9.24	9.50	12.03
SIMCOE, ONT	C	22.18	22.14	21.16	20.34	18.05	15.94	14.11	13.58	15.07	16.28	19.34	19.56	18.51
	K	2.00	2.04	2.04	2.16	2.12	2.09	2.01	1.94	2.10	2.11	2.17	2.08	1.87
	FO	2.93	2.03	3.00	2.64	2.74	4.93	5.55	5.44	5.32	4.35	3.33	4.11	3.87
SIOUX LOOKOUT A, ONT	C	12.76	13.05	13.54	13.98	14.00	13.67	13.43	12.60	13.51	14.58	13.65	12.13	13.45
	K	1.87	1.82	1.76	1.91	1.95	1.88	1.73	1.72	1.79	1.88	1.95	1.78	1.82
	FO	13.62	15.09	12.26	10.43	9.61	9.96	12.81	13.63	9.06	7.94	8.86	15.19	11.54
SUDBURY A, ONT	C	25.66	25.06	26.21	25.88	22.44	22.27	22.17	21.06	21.27	23.86	23.85	25.93	24.16
	K	2.06	2.09	2.18	2.34	2.33	2.19	2.16	2.28	2.11	2.19	2.27	2.21	2.12
	FO	3.59	3.80	2.16	1.46	2.10	2.39	2.41	2.25	3.78	2.84	3.54	4.25	2.88
THUNDER BAY A, ONT	C	18.21	17.49	18.17	18.91	17.49	16.21	16.01	14.91	15.75	17.08	17.26	16.95	17.10
	K	1.82	1.68	1.80	1.79	1.88	1.75	1.63	1.62	1.71	1.69	1.73	1.64	1.71
	FO	8.44	8.70	7.55	7.61	7.45	8.71	8.05	9.88	7.63	8.57	8.03	8.80	8.28



ANNUAL DIRECTED WIND ENERGY

TOTAL: 4501 MJ/M2

GORE BAY A, ONT

(MJ X 0.28 = KWH)

FIGURE 1

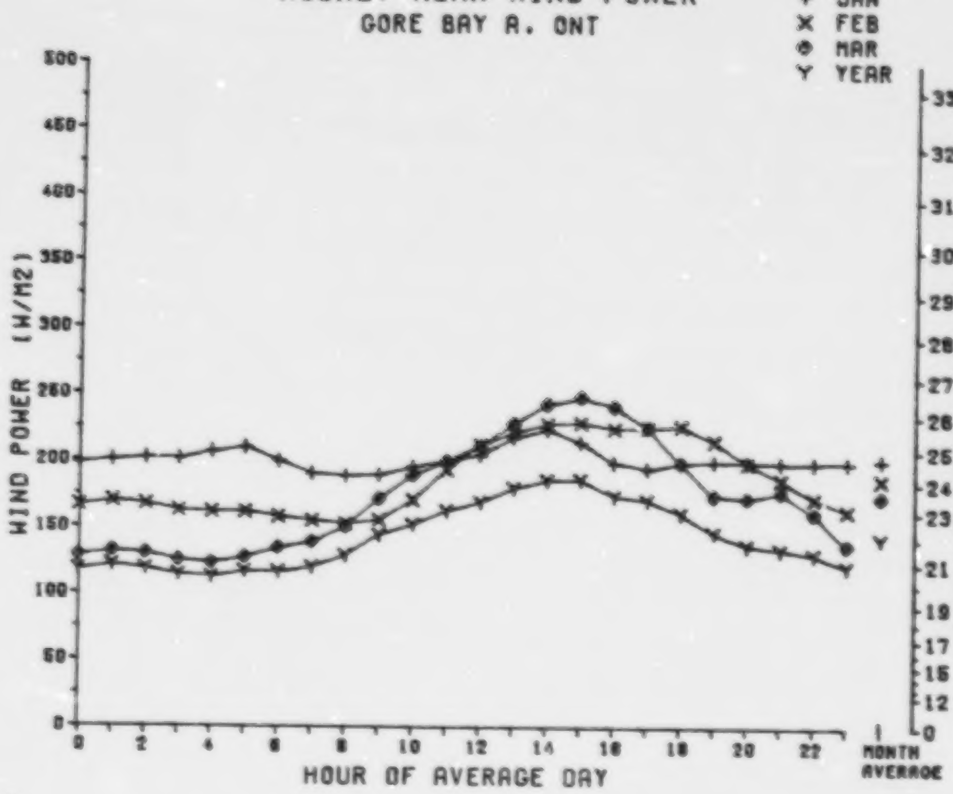
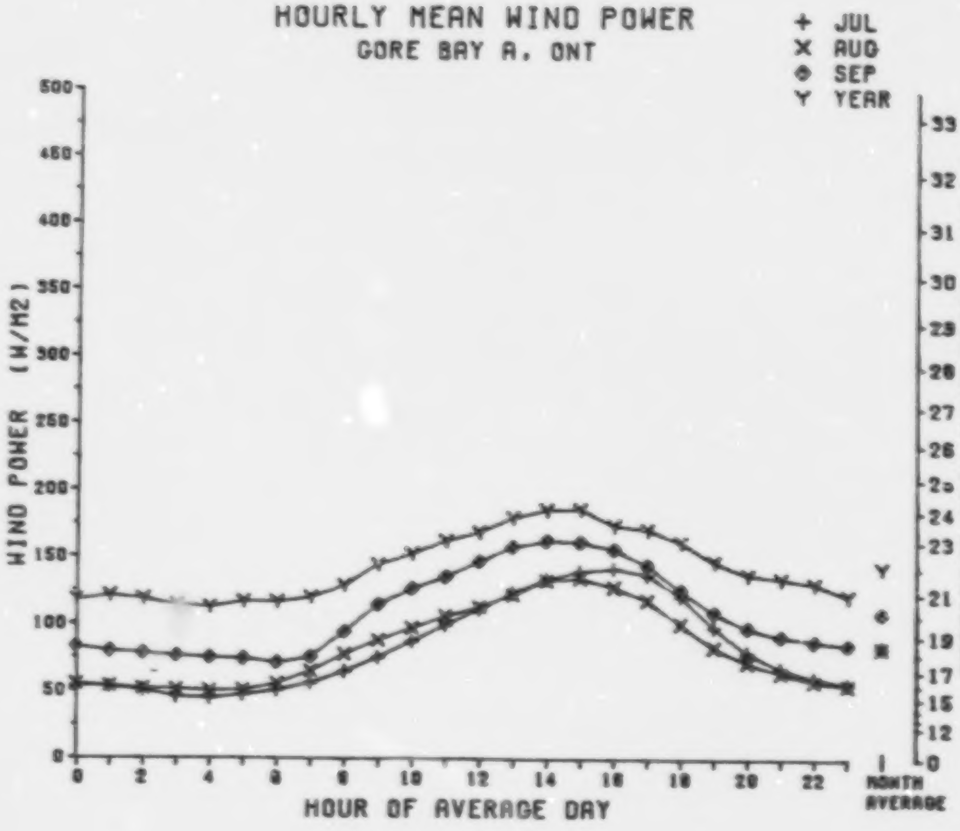

GORE BAY A. ONT
× FEB
◆ MAR
Y YEAR
WIND POWER (W/M2)
0
50
100
150
200
250
300
350
400
450
500
EFFECTIVE MEAN WIND SPEED (KM/H)
0
12
15
17
19
21
23
24
25
26
27
28
29
30
31
32
33
HOUR OF AVERAGE DAY
0
2
4
6
8
10
12
14
16
18
20
22
MONTH AVERAGE

FIGURE 2


HOURLY MEAN WIND POWER
GORE BAY A. ONT
+ JUL
× AUG
◆ SEP
Y YEAR
WIND POWER (W/M2)
0
50
100
150
200
250
300
350
400
450
500
EFFECTIVE MEAN WIND SPEED (KM/H)
0
12
15
17
19
21
23
24
25
26
27
28
29
30
31
32
33
HOUR OF AVERAGE DAY
0
2
4
6
8
10
12
14
16
18
20
22
MONTH AVERAGE

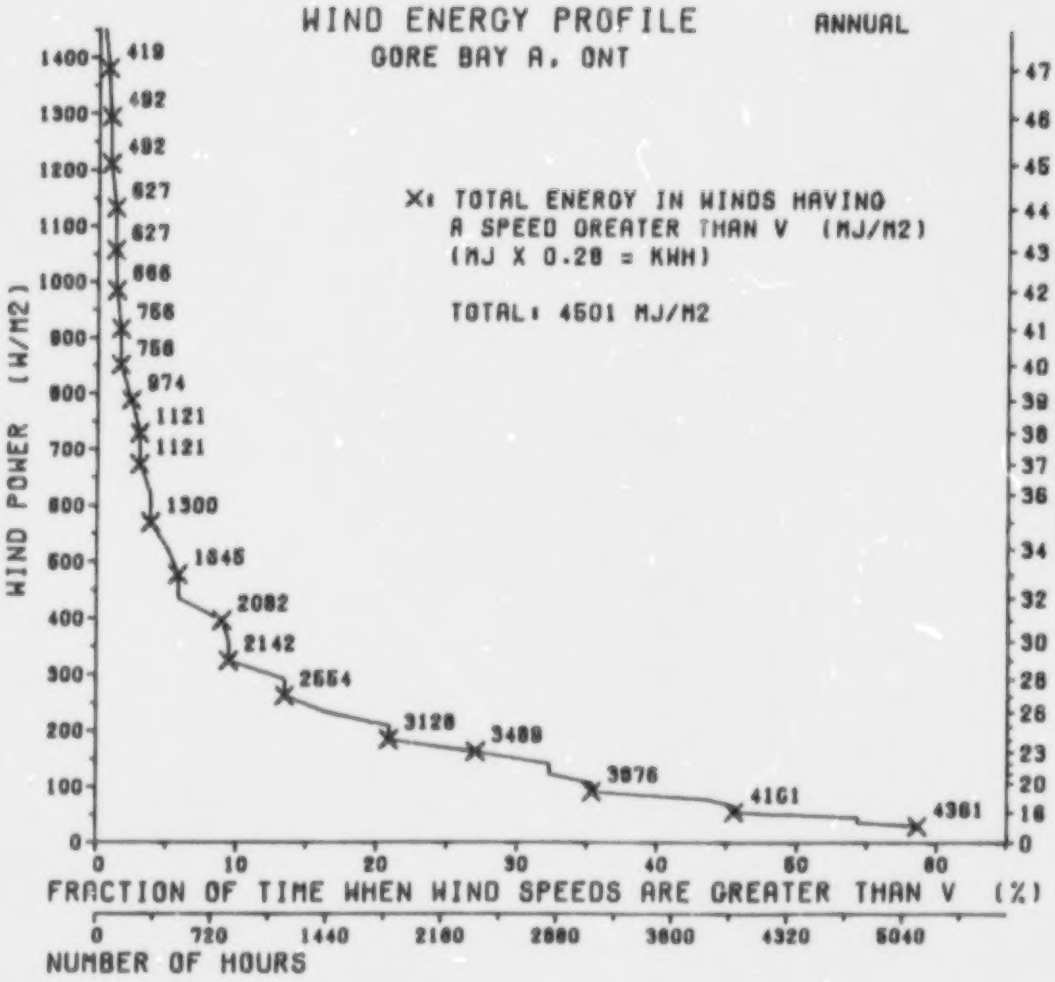


FIGURE 3

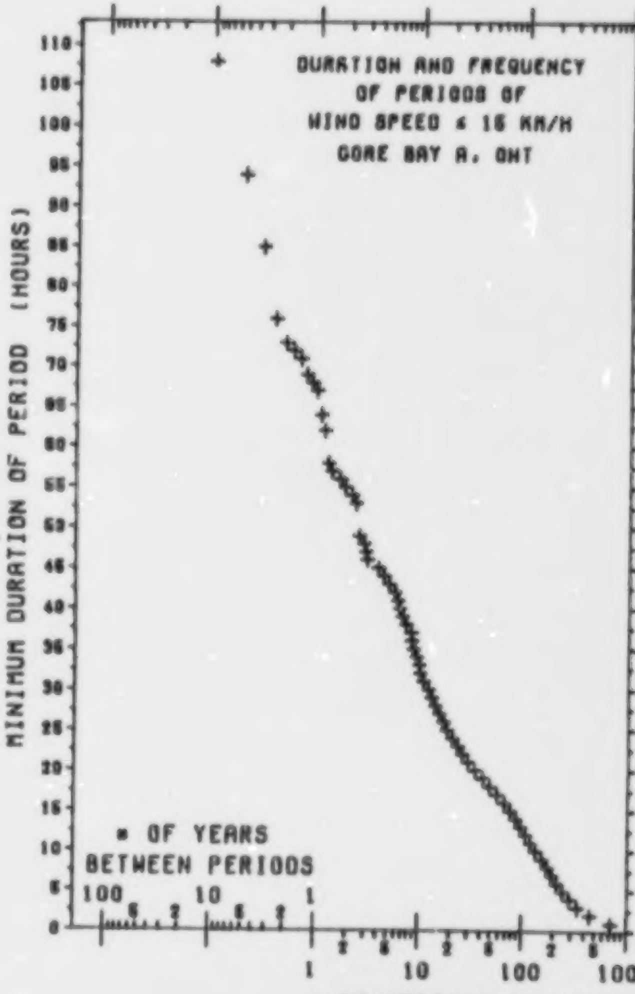
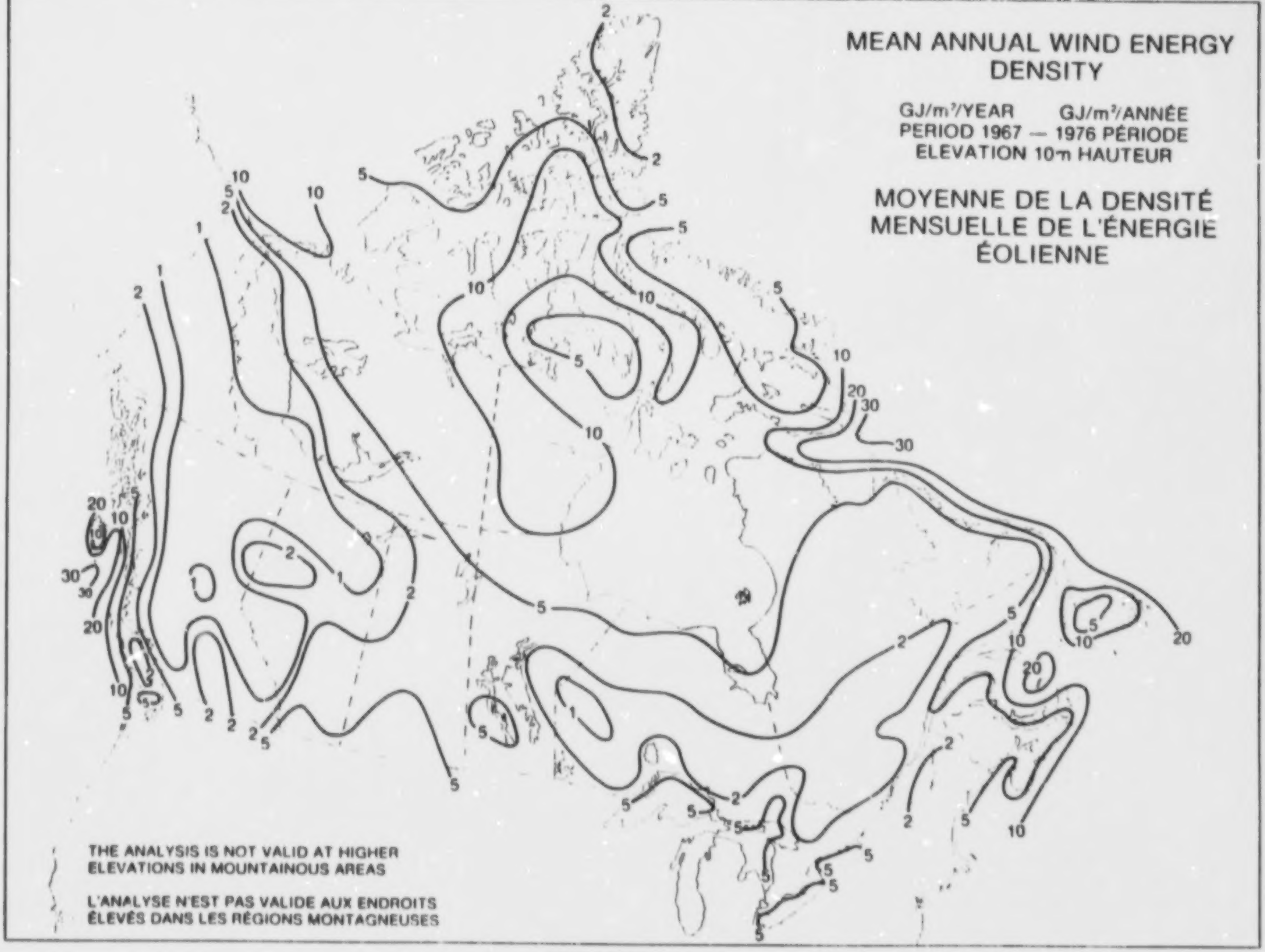


FIGURE 4



MEAN ANNUAL WIND ENERGY DENSITY

GJ/m²/YEAR GJ/m²/ANNÉE
PERIOD 1967 — 1976 PÉRIODE
ELEVATION 10-m HAUTEUR

MOYENNE DE LA DENSITÉ MENSUELLE DE L'ÉNERGIE ÉOLIENNE

THE ANALYSIS IS NOT VALID AT HIGHER ELEVATIONS IN MOUNTAINOUS AREAS

L'ANALYSE N'EST PAS VALIDE AUX ENDROITS ÉLEVÉS DANS LES RÉGIONS MONTAGNEUSES

FIGURE 5

PROMOD III EVALUATION OF THE WORTH OF GRID CONNECTED WECS.

Ken Slater
Slater Energy Consultants Inc.

SYNOPSIS

Evaluation of the worth of grid connected WECS requires proper recognition of the various ways in which the WECS affect the operation of a power system, and the interaction between the WECS and the other generation resources on the system. However, these requirements are no different from those for the evaluation of any other contemplated generation resource.

Since 1975, the author has been engaged, with others, in the development of the PROMOD III power system production and reliability model. This computerized mathematical model of the operation of a utility's generation resources is now being used by about 60 electric utilities in North America and Australia. In the U.S.A., utilities using PROMOD III own about 70% of that country's electric generating capacity. PROMOD III is used in generation planning, operational planning, financial planning and rate making, and one of its main roles is in the comparison and evaluation of various possible future generation resources.

During the past 5 years, the author has used PROMOD III to evaluate worth of grid connected WECS in studies for:

The Institute of Man and Resources (P.E.I.) [1].

Energy, Mines and Resources, Canada [2].

P.E.I. Energy Corporation [3].

In each of these studies, grid connected WECS have been evaluated in terms of both their effect on the system production costs and their effect on system reliability. In each case, it has been shown that the effect on system reliability, expressed as an equivalent "capacity benefit" has a real worth and must be included in any evaluation of grid connected WECS.

The use of a sophisticated power system production model such as PROMOD III, in the studies has made it possible to represent the WECS with a great deal of accuracy, including:

- site specific wind regimes
- month-by-month wind regimes
- the actual input/output function of the WECS
- the interaction of WECS and storage hydro generation
- the effect of WECS on the economic operation of thermal

resources and interchange

- the effects of different levels of penetration of grid connected WECS.

The WECS evaluated in the studies were both horizontal and vertical axis machines with rated outputs ranging from 0.7 to 4.75 MW. The studies showed that the main factors affecting the worth of grid connected WECS were:

- wind regimes
- choice of WECS rating
- other available generation options
- WECS penetration level
- the generation already installed on the grid
- future fuel costs.

The results of the studies were that the larger WECS under development at this time in the 4 to 5 MW range, do represent economic alternatives to conventional base load thermal generation resources in a number of areas of Canada where good wind regimes exist. However, to achieve this economic viability, it is necessary that:

- the larger WECS be developed
- the price of the WECS be as presently forecast
- the utilities be able to obtain the WECS at mass production prices not prototype prices
- the utilities have confidence that the WECS will have service lives comparable with other generation resources.

Given the above conditions, it is possible for WECS to become a significant generation resource in the Canadian Maritime Provinces, in Quebec, in Saskatchewan and in Alberta. It is also possible that WECS could help a province such as P.E.I. to stabilize its cost of electricity with indigenous resources.

In performing these several studies over the past 5 years, it has been realized that in the evaluation of unconventional power system generation resources such as WECS, it is far more satisfying for those performing the study and far more convincing for the evaluations to be performed with the same state-of-the-art techniques used to evaluate conventional resources. It is well worth the effort.

Work Backgrounder:

Ken Slater has worked in the electric utility industry for over 20 years in both Australia and North America. Since 1976 he has been president of Slater Energy Consultants, Inc. of Toronto, supplying specialized power system computer software and consulting services to utilities, governments, public interest groups, regulatory boards and public hearings, utility customers and other consulting firms.

The information that Atmospheric Environment Service is working on is input into the PROMOD III computer model which evaluates the worth of different power sources hooked into a utility grid.

PRESENTATION
****

Over the last five years I have been evaluating reasonably large wind machines in terms of being economic generation sources for reasonably substantial, traditional electricity systems. I have not been dealing with displacement of diesel generation at isolated sites. Rather, in our analysis, the wind energy systems have to compete with large base load equipment, such as nuclear or coal fired, not peaking generation like low load factor hydro, or gas turbines, the traditional sources of generation.

From 1975 onwards I was involved in the design and building of a large computer program for power systems to accurately model the behaviour of the generation system. It determines system production cost and system generation reliability. It includes arrangements like load management and interruptable loads. This model can also be used to analyse non-conventional resources such as solar backed up by electricity and wind turbines connected to the grid. This very extensive model is called PROMOD III.

PROMOD I was a program built in 1972 for Ontario Hydro. They still use it, working the poor thing to death.

PROMOD III is a much larger commercial program which we've been selling since 1976. It is installed in about 60 different utilities, most of them in the U.S., but several in Canada, one in Puerto Rico and one in Australia. We hope to expand overseas quite substantially into Hong Kong and another two in Australia. It is well accepted with pretty good market penetration. It appears at rate hearings and regulatory hearings of many sorts. I'm going to present what we found out in those studies and the types of relationships that have to be taken care of.

To do a thorough job of analyzing the worth of wind energy systems, one has to represent the behaviour of the wind turbines in a way which is very much time dependent, although it may not be completely chronological hour by hour. You must correlate your wind regime with the utility loads and other generation patterns on at least a monthly basis. If necessary you do it diurnally as well if there is a significant diurnal variation in the wind regime. You must represent the interactions that take place between the rather variable output of the wind energy systems and other system generation sources.

The main areas to come out of the examination:

First, there are production cost savings on other equipment. That is, there is energy produced that requires no fuel from other stations.

Second, there is a reliability benefit passed to the system. Even though wind energy systems may only operate at a 35% capacity factor, that operation still contributes to the reliability of the system and thus is a capacity benefit. You do save some installed capacity on the system.

When you include both of those you do get a substantial worth from the wind energy systems. From the results that we got, they can sometimes compete very well with traditional base load equipment.

The first study was done in 1980 for Energy, Mines and Resources Canada. They were interested in large wind turbines with capacities greater than 1 MW. A study done for them by Shawinigan on the projected costs of WECS (since we don't have the machines yet that we are talking about), indicated the larger machines offered great promise cost-wise.

FIGURE 1 WIND REGIMES AT CHOSEN REPRESENTATIVE SITES

	NOVA SCOTIA		NEW BRUNSWICK		SASKATCHEWAN	
Month	Canso	Halifax	Moncton	Saint John (Red Head)	Yorkton	Swift Current
January	6.6	5.7	5.8	5.7	5.1	7.3
February	6.4	5.6	5.6	5.7	4.9	7.2
March	6.3	5.9	5.8	5.6	5.1	6.8
April	5.9	5.5	5.5	4.5	5.5	6.9
May	5.5	5.3	5.2	4.4	5.7	6.8
June	5.3	5.0	4.8	4.4	5.2	6.4
July	4.8	4.5	4.4	3.7	4.7	5.7
August	5.3	4.5	4.5	3.6	4.6	5.8
September	5.1	4.4	4.6	4.4	5.2	6.6
October	5.7	4.9	5.1	5.2	5.4	6.9
November	6.2	5.3	5.4	6.1	5.2	7.0
December	6.8	5.6	5.6	5.7	5.0	7.4
ANNUAL	5.9	5.2	5.2	4.9	5.1	6.7

Wind speeds in m/sec. at 10 metres

Source: Canadian Normals, Wind. Environment Canada, 1975.

We started off by looking at Atmospheric Environment Service hourly wind regime data rather extensively (Figure 1). A fair bit of analysis was done on sites selected from the Canadian Normals - Wind Volume 3 (1955-1972), not the current publication but the previous one. We zeroed in on promising wind regimes such as in Swift Current, southern Saskatchewan, where there is already a DAF 50 kW machine. Other good areas were mainly in the Gulf of St. Lawrence.

We then chose several power systems to look at such as Saskatchewan because it offered some of the best wind regimes in the prairies, Nova Scotia, New Brunswick and Prince Edward Island in the east.

The Canadian Normals - Wind sites (Figure 2) do not have particularly high winds with wind regimes in excess of 5 m/s at 10 meters. Swift Current is substantially better. All of these wind regimes are better in the winter months than they are in the summer months which improves their value to Canadian winter peaking systems. This analysis also incorporates the wind speed distributions and the wind speed duration curves.

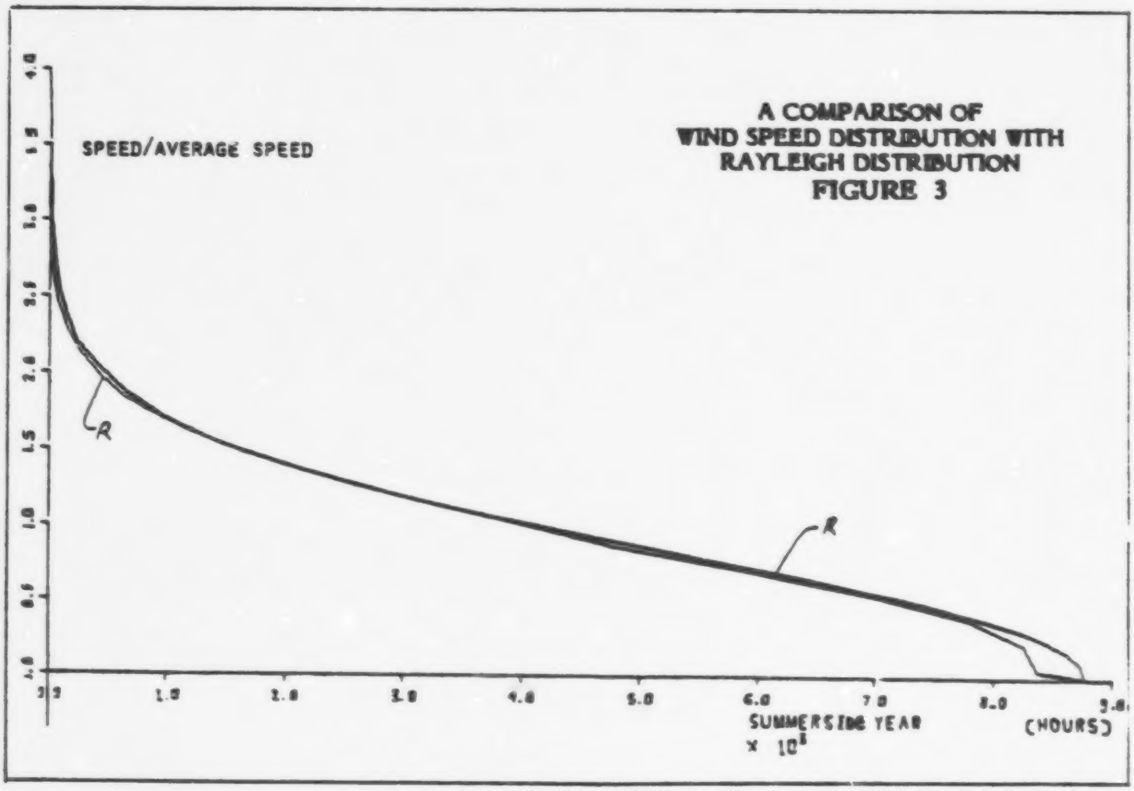
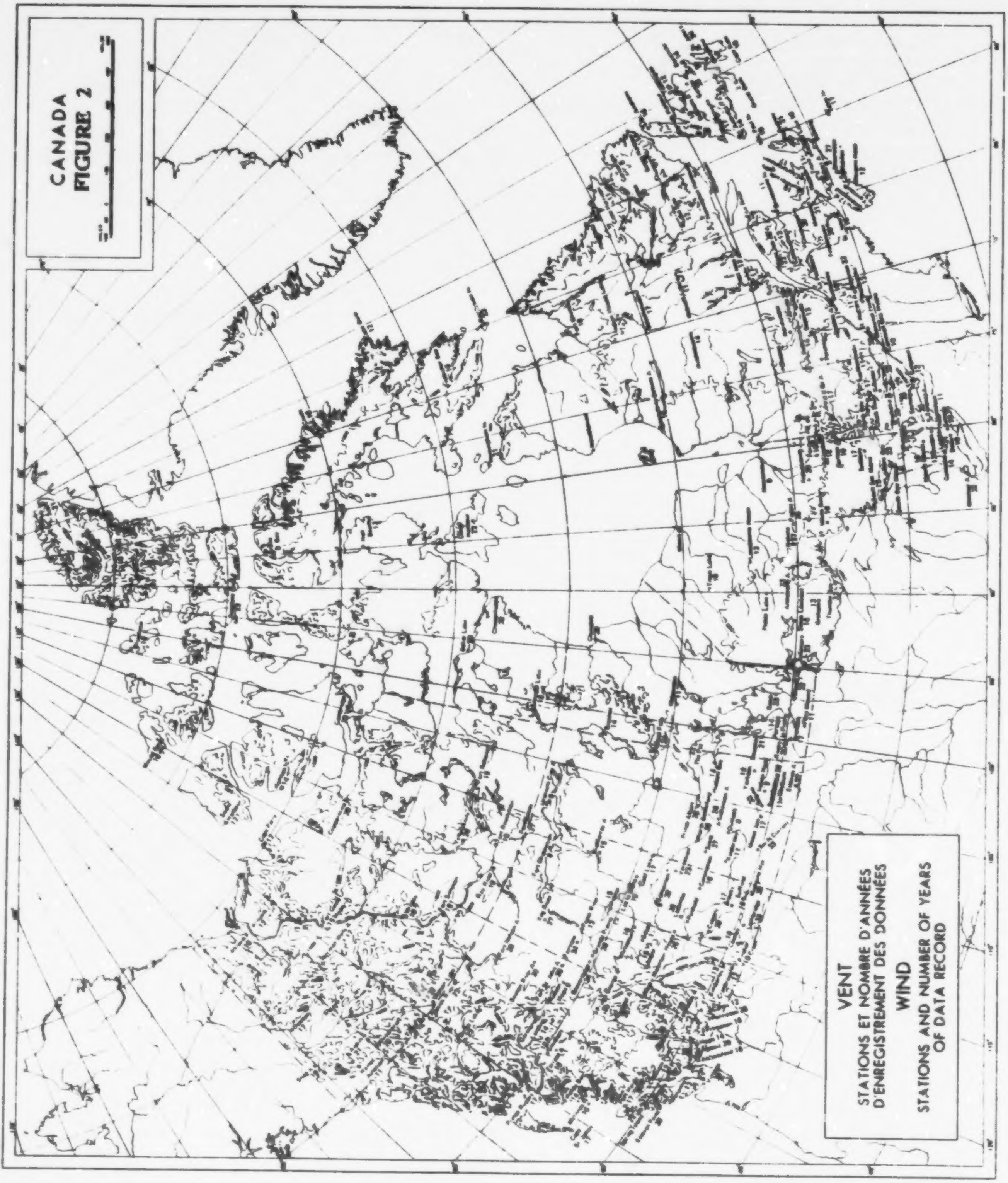

A COMPARISON OF
WIND SPEED DISTRIBUTION WITH
RAYLEIGH DISTRIBUTION
FIGURE 3

Figure 3 is a comparison between a Rayleigh distribution and the wind speed duration curve for Summerside, Prince Edward Island.



CANADA
FIGURE 2

VENT
STATIONS ET NOMBRE D'ANNÉES D'ENREGISTREMENT DES DONNÉES

WIND
STATIONS AND NUMBER OF YEARS OF DATA RECORD

There is a fairly substantial but not perfect measure of agreement. At some but not that many places, we were able to use a Rayleigh distribution to calculate mathematically the power output distribution curve for a particular wind turbine. Others were done empirically if the duration curve didn't look like something that we could put equations to. While you can do it either way, it is a bit more trouble to do them empirically rather than algebraically.

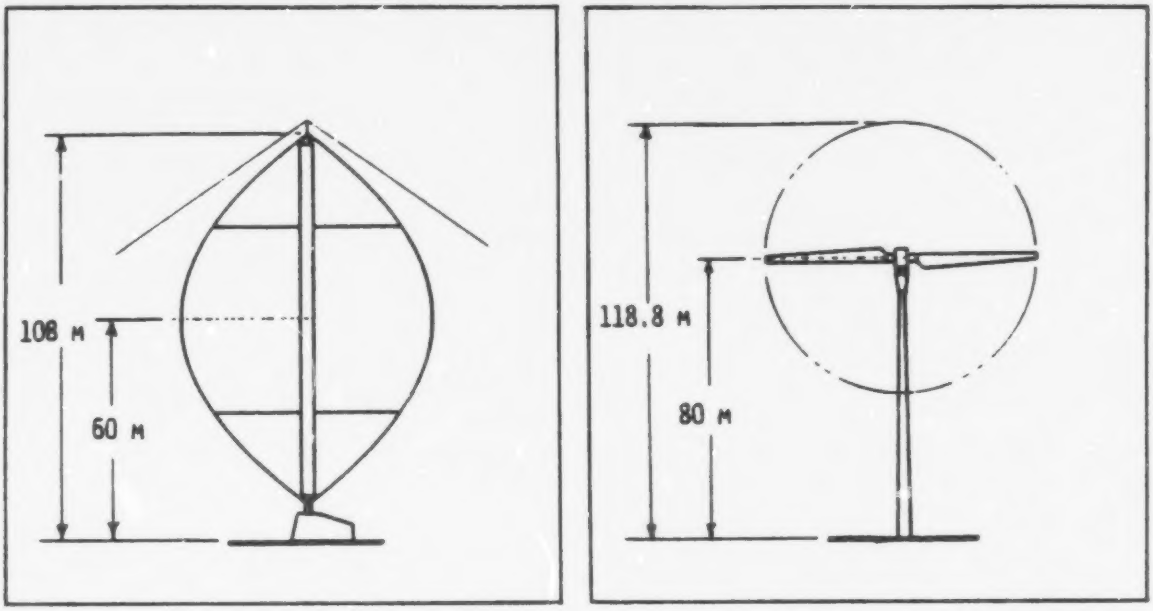


FIGURE 4 4000 M^2 DARRIEUS WTG

WTS4 WTG

In this study we looked at two machines (Figure 4). We started off looking at three but ALCOA withdrew their machine.

The Hamilton Standard WTS-4 was taken as read, for sale at 4.75 MW maximum output. It is a rather large machine, well over 300 feet tall with a swept area of 4,730 m^2. However, the diameter varies up and down a little bit between one brochure and another.

The other one is roughly the machine that is being developed on PROJET EOLE with a swept area of 4,000 m^2. The input/output calculation functions were obtained from Tom Ledwell of EMR. That machine was deliberately electrically downrated to a maximum output of only 2 MW. The Darrieus machine was downrated rather than the horizontal axis machine because Shawinigan's report suggested more potential for cost saving in a downrated Darrieus than for the horizontal axis unit. We got some interesting results as you'll see later. A 4 MW rating for the Darrieus achieves slightly better economics than for the horizontal axis machine because of the lower cost of a 4 MW Darrieus on a $/kW basis. A 4 MW Darrieus is almost exactly the same electrical output per square meter of swept area as the WTS-4. You'd get a bit more energy out of the WTS-4 but the Darrieus costs you less. We did a couple of runs to verify that the Darrieus would be a bit more economical than the WTS-4. There was not a lot in it. based on the cost projections that we had. Every curve developed for the input/output functions of the Darrieus machine appears to be on the conservative side. That seems to show up fairly clearly. Figures 5 and 6 show the input/output functions of the Darrieus and WTS-4 respectively.

Q There is no low wind cut-off?

A Not really. Doesn't matter, you just tail off where there is no percentage of energy anyway. It does not come down as sharply as the Darrieus machine does. It doesn't really matter whether you decide to cut if off or not for the outputs you get.

The wind regimes for about ten sites were combined with the input/output function of the wind turbines to produce a mathematical model of the output from each wind turbine on a monthly basis. A separate model was used for each site, for each month. Figure 7 shows the five state generator model used, although one could use more or less if one wants. Those five states with their probability of occurrence represented quite well the output distribution of the wind turbine.

FIGURE 7

FIVE NON-ZERO CAPACITY STATES

Each state is at the centre of a range of power output equal to approximately 20% of the maximum power output of the WTGs (e.g. for nominally 200 MW of WTGs, the power output ranges would be 0-40, 40-80, 80-120, 120-160, 160-200 MW, and the corresponding capacity states modelled would be 20, 60, 100, 140, and 180 MW).

This data was put into PROMOD III in several runs representing various power systems across Canada. We could direct the program to totally absorb this wind energy as it was available. This specification is called 'must run'. Another option was to coordinate the hydro on the systems with the wind. In other words, we could save the hydro if the wind was blowing.

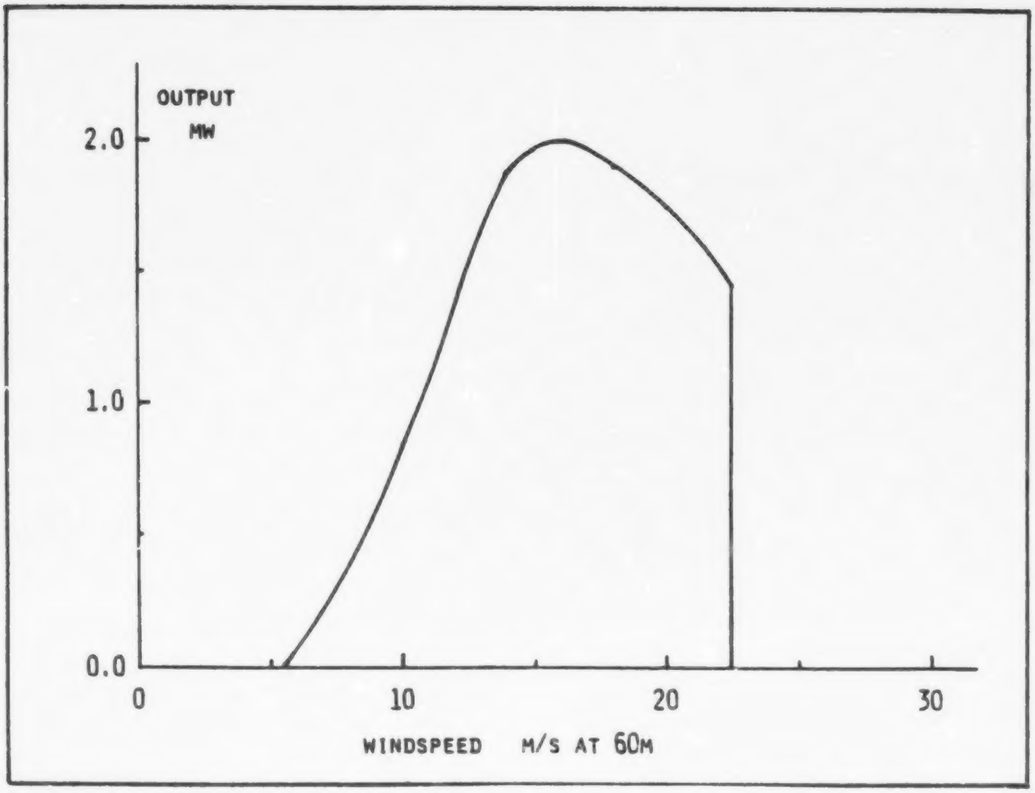


FIGURE 5 OUTPUT – WIND SPEED FOR 4000 M² DARRIEUS WTG RATED AT 2 MW

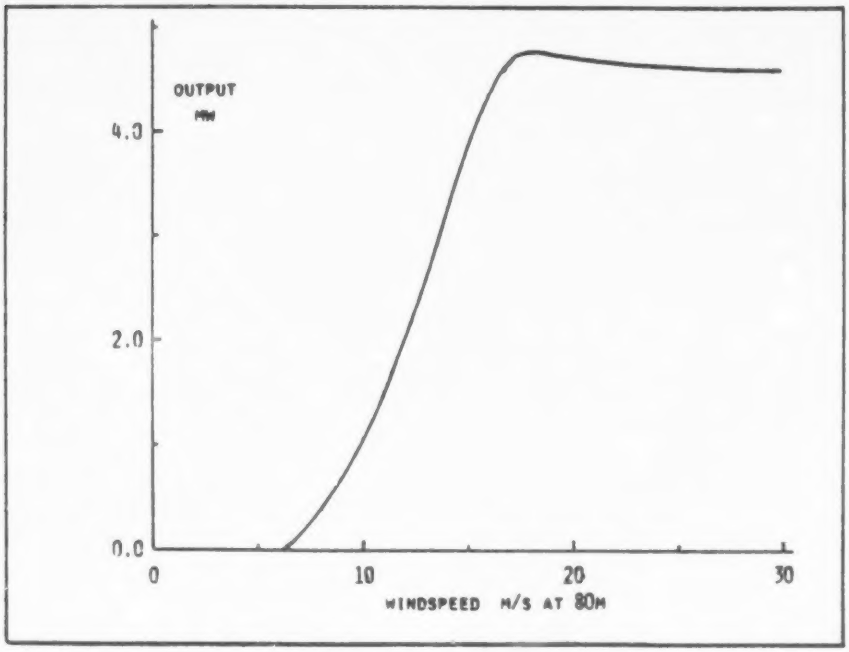


FIGURE 6 OUTPUT – WIND SPEED FOR WTS4 WTG

The actual system data was the then current system expansion plans for the Nova Scotia Power Corporation, New Brunswick Electric Power Commission, and Saskatchewan Power Corporation. The runs were done with their versions of PROMOD on their computers with their data and their personnel so they were valid runs from their planning departments. We studied the worth of various amounts of wind capacity at various sites on each one of their systems in place of some of their planned expansion.

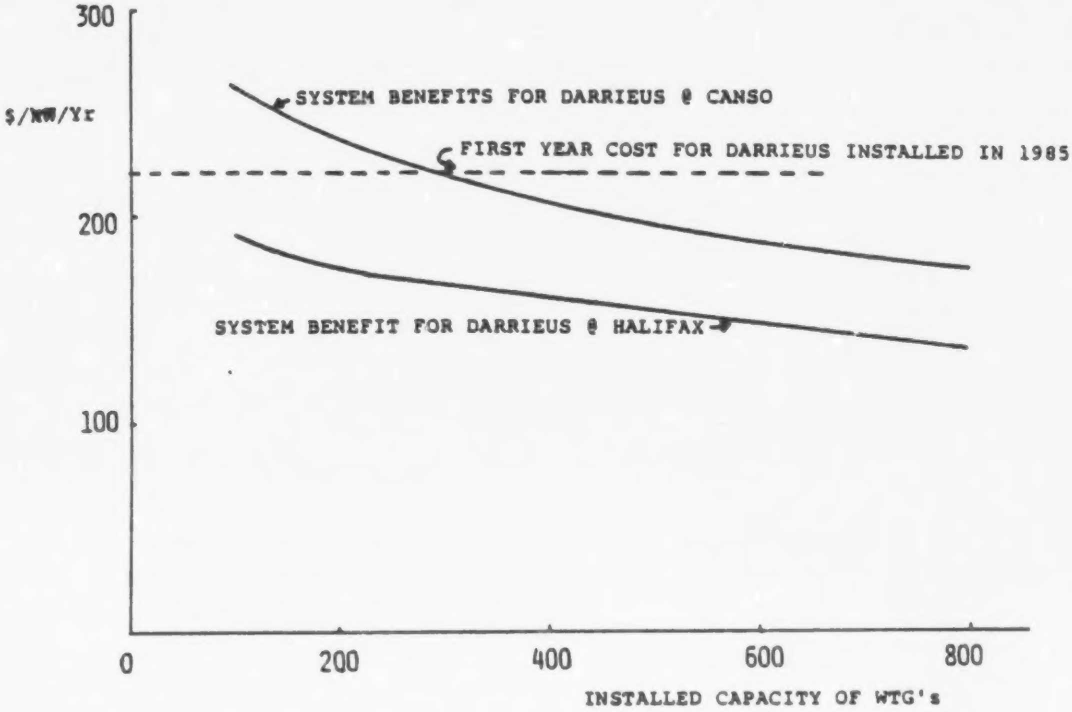


FIGURE 8 TOTAL FIRST-YEAR COSTS AND SYSTEM BENEFITS FOR WTGS INSTALLED IN 1985 IN NSPC

Figure 8 is a sample of some of the PROMOD III output for the 2 MW 4,000 m^2 Darrieus at two sites in Nova Scotia: Halifax airport, - a pretty lousy site and Canso - a somewhat better site. We looked at the total system benefit both in production benefits and reliability benefits putting dollars on the saving in capacity to the system by not having to install some other type of generation. These were graphed against the amount of wind turbine capacity put on the systems. Notice the up to 800 MW of wind turbine capacity on the less than 2,000 MW Nova Scotia system in 1985. That is a lot of penetration. On this graph the first year annual costs of those wind generators are compared with the system benefits. In the first year at a site like

Canso, the wind turbines could pay for their annual upkeep on 200 MW of wind turbines. Those wind turbines are production machines, not prototype machines, priced at Shawinigan's evaluation of the 100th unit costs.

Q On that graph is it better to be higher of lower?

A It is better to be higher.

Q So, in other words, by the way the graph is going, it is better not to put in anything at all?

A No. The graph says there that even in the first year of operation, you could pay for something in excess of 200 MW of badly matched underrated Darrieus capacity at Canso. That is first year cost. A lot of new equipment you put on power systems does not carry its own weight in the first year. I've got another graph that will show you what it looks like after the first year or so.

Q Why is that? Is that because there are capital costs involved?

A Well, it is because of the way utilities generally speaking "absorb the cost" of power system apparatus that they put on their system. They use straight line depreciation. They charge interest on remaining capital. You have the same depreciation in dollars in the first year as you have in the last year. The interest in the first year is 30 times as high as it is in the last year. The O&M costs rise a little over the life of the apparatus.

Q One thing that confuses me is that system benefits go down with increase in capacity. Please explain?

A The average system benefit goes down with increasing capacity. That's average in $/kW/year. As you approach saturation, as you increase the amount you put in, you get less benefit back from each additional kilowatt that you install. That is on a per unit basis. It would rise if it were on a total power basis.

Figure 9 is a look again at Nova Scotia in 1999 using the same machine. It shows the Darrieus at the top and the WTS-4 at the bottom. The Darrieus machine, with installed capacity close to 400 MW, can be supported in the first year because in 1995 the load is higher and the fuel costs are higher.

The WTS-4 machine was given a much higher electric rating for the same swept area. The Darrieus wind turbine was operating at about half a kW per square meter whereas the WTS-4 is rated at 1 kW per square meter swept area. We found invariably at every single site that there is no point in underrating. When you

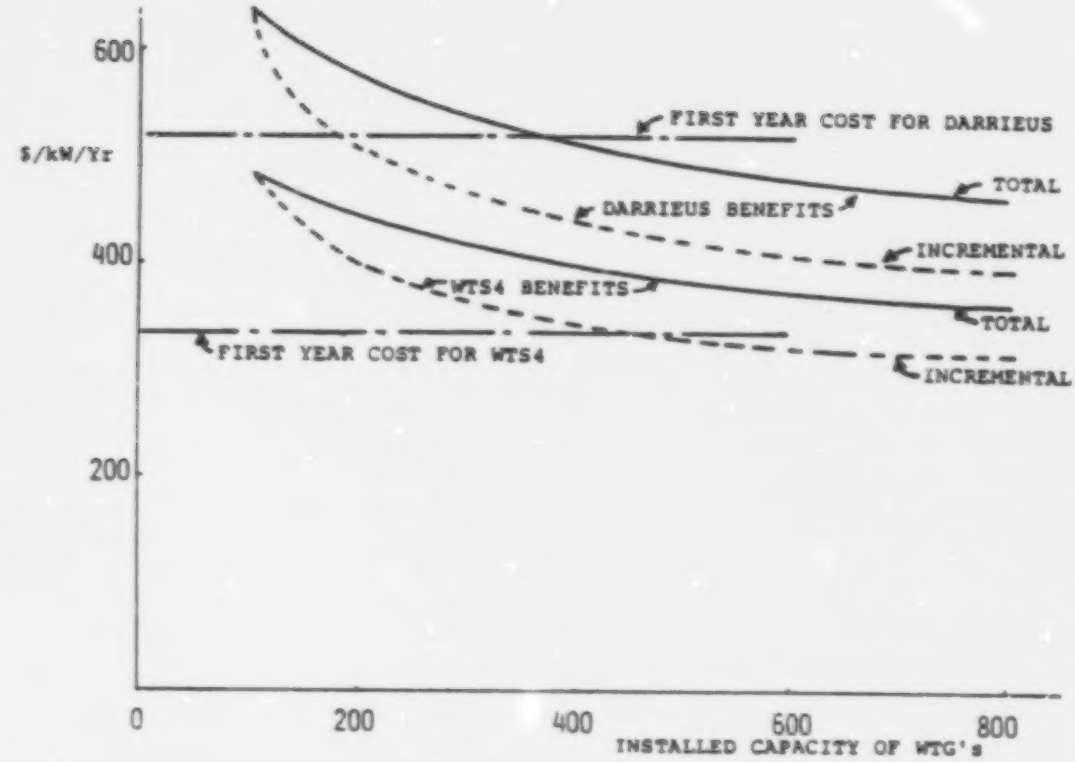


FIGURE 9 TOTAL FIRST-YEAR COSTS AND SYSTEM BENEFITS FOR WTGS INSTALLED IN 1999 AT CANSO IN NSPC

underrate you have a lower cut-in and the wind turbine operates for a higher percentage of the time, but you are losing too much energy compared to the cost saving. It just did not pay at all to be underrating the machine. The improved percentage of the time that the machine produced some output was not as valuable to the system as the higher outputs that were produced with a machine rated much higher. It was quite instructive to do that. The only trouble with doing it is that it tends to indicate the WTS-4 is better than a Darrieus and I assure you it is not. We did not do runs with the Darrieus rotor at about 1 kW per square meter.

Figure 10 (FIGURE NOT AVAILABLE) is Sydney, Nova Scotia which was even better than Canso. A little bit further out into the St. Lawrence area with a somewhat higher wind regime. All of these are land sites that can be connected to the main grid. This cuts out a lot of the coastal sites in B.C. because there were no decent sites on land close to the main grid. Some people get a little offended when we say B.C. was a wash-out, but for grid connected systems it was.

FIGURE 11 COMPARISON OF ACCUMULATED DISCOUNTED LIFE-CYCLE COSTS IN NOVA SCOTIA

	Discount Rate (Real)			
	2%	4%	7%	10%
Nuclear Plant (75% C.F.)	1.00	0.88	0.77	0.70
Coal-Fired Plant (75% C.F.)	2.77	2.25	1.74	1.43
WTS4 – 400 MW at Canso	0.95	0.93	0.92	0.90
WTS4 – 400 MW at Sydney	0.81	0.79	0.78	0.77
WTS4 – 570 MW at Sydney	0.88	0.86	0.85	0.84
WTS4 – 760 MW at Sydney	0.91	0.89	0.88	0.87

Annual Average W/S at Canso is 5.9 m/sec.
Annual Average W/S at Sydney is 6.3 m/sec.

The discounted life-cycle cost of nuclear plant at 2% real discount rate is used as the reference value.

Figure 11 is a different type of analysis applying life cycle costing with a real discount rate. In this case the rate was several percentage points higher than the normal cost escalation rate. I think the federal people generally would like to see us out in the 7% range, not down around about 2% to 4%. The utilities commonly use 2% to 4% in their own evaluations. In other words, their discount rate looks like their interest rate which is about 2 1/2% to 3% higher than the inflation rate. The economists like to see us further out again. We covered the range from about 2% to 10%. This is Nova Scotia again where we compare coal-fired with nuclear power from a second Le Preau unit. A second Le Preau unit was used because the first one was too expensive. They've got good lines on coal-fired generation costs in Nova Scotia because they are currently building at Lin Gans (?). We just increased the penetration of wind energy systems at Sydney and Canso. To understand this chart relative to discounted life cycle cost, you have got to look for where the one is on this chart. Everything is being compared to the life cycle cost of CANDU at a 2% discount rate. If you see something lower than that it means that the cost is lower. The life cycle cost of nuclear if you use a 10% discount rate is .7 compared with 1. When you compare coal with nuclear or wind, it is roughly out of the question for Nova Scotia. The politics of work on Cape Breton, keeping the coal mines going, keeps it in their generation plans. The WTS-4 was used on this type of comparison because it was representative of the type of power production that you would need, whether Darrieus or horizontal axis. The more desired rating was about 1 kW/m^2 so we used the WTS-4 in this comparison. A high penetration of wind is still quite competitive with the nuclear at a 4% discount rate. It was a bit more expensive at 7%. If we drop down somewhat in the penetration you can see that at 5% the wind would still be ahead at Sydney. At Canso it didn't compete against the nuclear quite so well, but the site at Sydney could be quite competitive with nuclear.

Q Could you explain the reasons why higher discount rate nuclear would work out cheaper compared with wind?

A It tails off more rapidly than the wind does. This is because the fuel costs and the yearly O&M costs for nuclear are significantly higher than the O&M costs for the wind. Almost all of your costs for the wind are up front in the discounted fashion. For nuclear, only 80% are up front. For coal maybe 40% are up front. Coal tails off very rapidly. It has dropped to almost half by the time you get out to a 10% discount rate. The nuclear is down to about .7 but the wind doesn't shift very much at all. That is because of the low assumed O&M costs in these studies for the wind. There is no fuel or heavy water upkeep or anything like that to charge for the wind.

Q What were your assumed O&M costs and were they expressed as a percentage of installed value?

A I do have the figures, but I will show them to you later. We were using estimates put together mainly by Ontario Hydro with some assistance by the special studies branch of Energy, Mines and Resources Canada who have done some work on the social cost of displacing electricity, gas or oil. They did some scaling with the help of Ontario Hydro on how the O&M costs would rise for stations that only had one or two units in them as opposed to Ontario Hydro's 40 units. How the construction costs would differ if you built 2 unit stations in Nova Scotia or New Brunswick as opposed to the 40 unit stations in Ontario.

Q Clearly more sophistication than assuming a percentage, that's really what I was after.

A The O&M costs were just a little higher in the Maritimes. Capital costs were somewhat higher due to building smaller stations.

Q I assume O&M means operation and management?

A Operation and Maintenance. Management comes under overhead. Please call me up for that sort of thing.

Q For the non-economists here, could you just define the discount rate?

A I'm a non-economist. If the inflation rate were 7% and I had a 4% real discount rate it would mean that I would present worth my future expenditures back to the present at 11% annually.

Q Take a dollar and work on it?

A A dollar spent ten years down the road is not worth very much today. The higher the discount rate, the less it is worth right now. For example, a dollar spent next year is worth 90 cents today. That is a 10% absolute discount rate. I have used relative here to get away from the fact that during the time period that we were looking at, the inflation rate is assumed to be sliding downwards (as all economists tend to hope) and which is happening. The best way of expressing it is with a real discount rate, real meaning that you back out the effect of inflation and come to a constant dollar type discount.

Q Coal goes down because your initial investments are lower but your annual expenditure is far higher. What you have to discount now is what you are going to be spending later?

A Fuel costs for a coal fired station are about ten times what they are at the nuclear station. That's a rough number. It is not 100 and it is not 1, it is about ten, fifteen, or five, depending on where you are.

Q And nuclear investment is a lot higher?

A Nuclear investment is somewhat higher but not too much higher. Surprising. Although in the next study we had to do a little fiddling with those numbers to make people believe.

Figure 12 is another chart for New Brunswick for imported coal. New Brunswick does not have enough coal to do anything more than they are doing now. We were looking at Moncton and another site, Miscou which sticks out into the St. Lawrence area. Miscou was the best wind site that we could find in New Brunswick. It was on reasonably level ground and near the grid. The wind option was significantly better than the coal-fired alternative which we were quite pleased with.

Q Are the wind speeds quoted at the 10 m height or the mid-rotor height?

A All the wind speeds were taken at the 10 m height for standardization because the equator height on the Darrieus was different from the hub height on the WTS-4. You'd get all mixed up if you didn't quote it at a standard height.

FIGURE 12 COMPARISON OF ACCUMULATED DISCOUNTED LIFE-CYCLE COSTS IN NEW BRUNSWICK

	Real Discount Rate			
	2%	4%	7%	10%
Coal 200 MW Local Coal-Fired (Intermediate Load Generation)	1	0.82	0.65	0.55
Wind 600 MW – Darrieus at Moncton	0.96	0.95	0.93	0.92
Wind 600 MW – WTS4 at Miscou	0.54	0.53	0.52	0.52

Annual Mean W/S at Moncton is 5.2 m/sec.
Annual Mean W/S at Miscou Island is 6.3 m/sec.

Figure 13 shows the prairie results which were very surprising. We thought that coal might be number one because of the low cost of coal. But, unfortunately, in Saskatchewan they've got to spend more money on their plants because the coal is so poor that the boilers become bigger and more troublesome with higher O&M. We compared this to 950 MW of installed wind capacity in the year 2000 at Swift Current. That represents over 25% of the system, a fairly high level of penetration. Wind again is somewhat better than the coal plant and better than the nuclear plant. Unless you get way up to 10% discount rates then nuclear beats the coal, but I don't think anybody really wants to use a 10% discount rate.

FIGURE 13 COMPARISON OF ACCUMULATED DISCOUNTED LIFE-CYCLE COSTS IN SASKATCHEWAN

	Real Discount Rate			
	2%	4%	7%	10%
Nuclear Plant (80% C.F.)	1.0	0.88	0.77	0.70
Coal-Fired Plant (80% C.F.)	1.54	1.29	1.06	0.91
Wind – 950 MW WTS4 at Swift Current	0.77	0.75	0.74	0.73

FIGURE 14 EFFECT OF CO-ORDINATION BETWEEN HYDRAULIC GENERATION AND WIND GENERATION, NBEPC

	Capacity Benefit/Year		Energy Benefit/Year	Total Benefit/Year
	(Firm MW)	($M)	($M)	($M)
1985 – Darrieus at Moncton				
– Unco-ordinated	60.8	6.7	61.1	67.8
– Co-ordinated	83.5	9.2	68.5	77.7
1995 – 400 MW Darrieus at Moncton				
– Unco-ordinated	67.6	14.5	62.0	76.5
– Co-ordinated	86.2	18.5	75.3	93.8

Figure 14 illustrates varying the coordination between wind and hydro. We did some coordinated and uncoordinated runs with the computer model. 'Coordinated' means that the hydro was used before the windmill. The release of water from the hydro storage would be decided without regard for what the day was going to bring in terms of wind. So there was no coordination. In the 'coordinated' case, the wind blows first, then water releases help to fill in the gaps between windy periods. There are limits to this of course. Coordination raises the benefit part considerably. The change in benefits was even better as you went further out in time. One of the reasons was that the system load had grown a little by then and the load had become a little peakier by then. We get more benefit out of being able to use the hydro at a lower load factor because the wind would take out some of the load.

Q When you said benefit you were comparing it to what would be installed nuclear capacity or other thermal?

A In working out benefit, we postulate a system then superimpose the wind on it. The determination of how much is saved in production costs would provide the system with the equivalent of so many MW of generating capacity. Because we have an energy benefit to take into account, we would price that capacity saving at the lowest possible cost to provide generating capacity to handle peak on the system. In other words, an equivalent reliability benefit at the lowest possible cost which was gas turbines. The capacity benefit established for the system would be priced at gas turbine rates. Combining the two benefits results in an overall benefit for the system. You do not have to compare the system benefits of wind with the system benefits for nuclear and coal in exactly the same way in all cases. Nuclear generation provides so much energy benefits or production cost benefits to the system and so much capacity benefit which again is priced at gas turbine rates. This is to establish a common measurement so that you can compare oranges with oranges and not with apples.

Q Are you saying, for example, that by 1985 when we save .77 dollars per year as compared to...?

A No. What we want to do is compare the relative benefits from the coordinated state versus the uncoordinated state between the wind and hydro. That is, to show that there is considerable benefit derived by having wind and some hydro on a system that is not too constrained, that is operating at a low load factor. You can get a higher benefit from the wind on this system than on a similar system with fuel costs, construction costs, etc. You get a higher benefit on a system with the hydro because there is some potential to be gained by coordinating the wind and the hydro.

Q Does that imply some knowledge of the wind? Do you have to have a 100% accurate forecast 24 hours in advance? There is no lead time for hydro?

A You can not assume it for every hydro in the system, but hydro with sufficient storage can be managed quite well on a day to day, even week to week basis without any trouble. If the wind is blowing, you just do not generate as much with hydro. The water stays there for tomorrow or the next day or next week. Days of accurately forecast lead time are not required for this type of coordination, maybe a few minutes or half an hour. This is only for hydro stations which have the storage. The stations that do not have the storage get dispatched the same way with or without the wind.

Figure 15 shows annual system benefits and costs. This shows that the benefits from the wind are significantly affected by the fuel costs of the system. The difference between the two charts is the assumption whether the New Brunswick system Coleson Cove station, which is currently oil-fired, is converted to coal-fired by 1985. It won't be by 1985 but we wanted to do an evaluation of that year. The gap would even be wider in 1990. The benefits are significantly different, their ratio is quite different, particularly in the early years. If you follow along the bottom axis of 'number of years', even with the cheapest alternate cost on the system - Coleson Cove on coal firing, the crossover of the annual costs to the annual benefits of quite a substantial amount of wind generation (the Darrieus, not even the WTS-4) occurs at about six years. For the first six years you lost money and for the other 24 years you gained money. With Coleson Cove on oil firing, it took about 2 years for the benefit to pass the cost. This figure also shows you how the cost of the wind turbines was

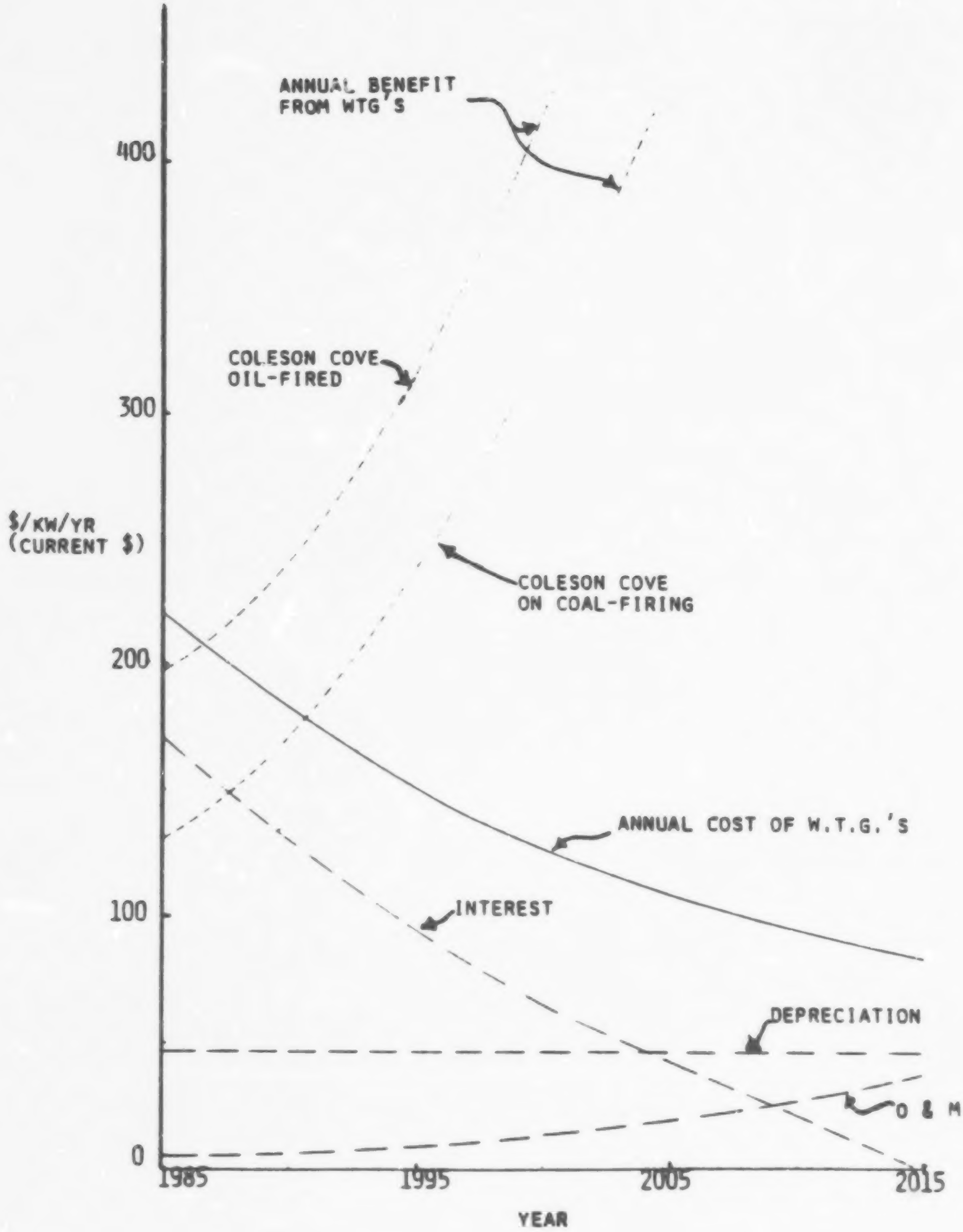


FIGURE 15 ANNUAL SYSTEM BENEFITS AND COSTS ASSOCIATED WITH 4000 m² DARRIEUS WTGS INSTALLED AT MONCTON, NBEPC, IN 1985

made up on a year by year basis, the costs imposed on the customers of the power system. Interest declines very rapidly down through there. The bend in the curve over the years 1985 to 2015 is caused by the change in interest rate in our study assumptions. If the interest rate had remained constant, that would be a straight line on interest. Operation and Maintenance expense rose quite significantly due to inflation. Straight line depreciation methods remain flat across the whole 30 years. When you add them all up you get that solid line. The annual costs, not in constant dollars, but in dollars of the year, decline rather significantly as you go across over the life of the apparatus. The power system people would charge those costs to their consumers.

Q O&M goes up because of inflation and not because of the aging of the equipment?

A No. To keep apparatus on a power system in working order, the assumption is made that the equipment doesn't really age. It improves in the first few years after all the components go through their 'infant mortality' stage. It matures in the first few years. For a nuclear plant it is about 3 years to maturity. For a less complicated piece of apparatus, sometimes one year. For a wind turbine it would probably be one year to maturity. This usually shows up in the 'Forced Outage' rates and the amount of time spent on semi-emergency maintenance. Then the assumption is that the expenditure is made on that apparatus to keep it in the same good working order until it is decided to retire it or to reduce its duty. For a base load piece of equipment, you are not going to reduce its duty, it travels on that way until you retire it. You retire it when it gets to the stage that it costs too much to maintain it. Instead of retiring them they often spend quite a lot of money on them and start off a new depreciation account for another 15 years. It is not to be assumed with any piece of power system apparatus that it is finished at the end of its depreciation life. That would mean that after 30 years every single thermal generator would be shut down "the day after", and they're not. There are thermal generators on the system that are 60 years old around the country. They were depreciated 30 years ago. But that just illustrates the relationship between first year costs and benefits, which was shown on the other graphs. It is nothing to get alarmed about if the first year benefits are not as high as the first year costs. You do that type of analysis to see what sort of burden a new piece of apparatus has on the system's customers in the first couple of years. Then it must be determined whether the customers can tolerate that for the benefits they will receive in later years.

Having evaluated 3 sample systems across the country, figure 16 shows what the prospect was for the wind generation,....

******Tape changed*****

FIGURE 16 REALIZABLE POTENTIAL FOR WTGS IN ELECTRICAL UTILITY SYSTEMS

	2000	2020
Newfoundland	400*	800*
Nova Scotia	700*	1 400*
Prince Edward Island	75*	150*
New Brunswick	970	2 100
Quebec	2 500	10 000
Ontario	–	–
Manitoba	–	–
Saskatchewan	1 000*	1 800*
Alberta	300	1 000
British Columbia	–	–
Canada	6 000 MW	17 000 MW

WTG capacities are in terms of machines rated at about 1 kW/m^2 of swept area and built under mass production conditions.

* Potential is limited by "largest unit" security limit.

...In the final report...the discussion here. I think the total is about 17,000 and not 17,500. There is not much difference between these numbers and the final ones. These are the years across the top. Newfoundland could well benefit from wind, as could Nova Scotia, Prince Edward Island and New Brunswick. All of them could benefit by the year 2000. The cost picture on all of those utilities was changing through to the year 2000, since fuel costs were rising. Oil costs were assumed to be increasing at greater than the rate of general inflation and so were coal costs whether imported or Nova Scotia coal.

In fact, we found out local coal costs more than they are actually charging the Nova Scotia Power Corporation. They could not charge them any more as then it could be imported for the same price. The Nova Scotia Cape Breton coal has been pegged in price by the cost of imported coal along the eastern seaboard.

Quebec had a toss up choice between adding nuclear generation or wind generation after it had developed a few more of its hydro sites. Not too many more hydro sites because costs are rising rather rapidly as they move into worse and further away sites. It is unlikely a utility the size of Hydro Quebec would invest all of its non-hydro generation in one single technology. The projections in this case are on the basis of splitting between the best two alternatives for them which are nuclear and wind.

Ontario and Manitoba very little. Most of the sites with the exception of the Sudbury area are just not good enough. In Ontario the cost of constructing alternate types of generation is a lot less. You can get differences of 30% in the $/kW for nuclear and large coal-fired through economies of scale and economies of institutional debt financing and inflation.

Saskatchewan has good potential and Alberta has some potential, though not as high as Saskatchewan's. British Columbia has just got a pair of dashes because their grid doesn't come anywhere near its good sites and won't for some time. The potential there from a marketing perspective, is very, very high for wind turbines if the costs come down to expectations and the performance comes up to expectations.

On a very different level from the rather large systems like Saskatchewan's, figure 17 (FIGURE NOT AVAILABLE) summarizes a very recent study in Prince Edward Island which compared conventional and unconventional resources. In this case the baseline alternative is a little different. All of the alternatives for generation in Prince Edward Island were compared with making a firm power purchase contract with NBEPC over the cable across the Northumberland Strait. They could buy all they want from New Brunswick.

We took the firm purchase arrangement...(static)...and energy price with the New Brunswick system incremental cost. This is the standard type of arrangement in the industry today. Each of the other alternatives were compared with that alternative.

Figure 18 (FIGURE NOT AVAILABLE) is cost benefit ratios comparing the alternative of buying more from New Brunswick against additional resources on the Prince Edward Island system, for capital cost estimates for nuclear, coal, wood fired, and wind turbines vintage 1979 - 1980. This set of cost benefit ratios indicates participation in ownership of a nuclear plant, off island, as the most beneficial and wind turbines the next. The other two: participation in a large lignite coal-fired station, say in Nova Scotia, or putting a wood fired plant on Prince Edward Island itself, indicate the benefits are less than the cost. We did it again later, vintage early 1982, with some updated capital cost estimates which were not quite as well founded. The red figures give those values. Again, the only two that make any sense for Prince Edward Island were the CANDU and the wind. The wind site we used on Prince Edward Island was Tignish.

We expect to be able to find better wind regimes in Prince Edward Island than what was recorded there. The description of the measuring site at Tignish says the anemometer is well exposed on an open farm in an open field. The surrounding countryside is flat. It says situated on a small cliff to the southeast, winds from the southeast are affected by the sheer cliff.

Q What is the cost figure there?

A 1.54. It is just 10% different. When I am looking at a time period out to 1995 and looking at capital cost estimates ten years into the future, ten percent doesn't really mean anything. Plus there are better wind regimes than that. Nevertheless it is a bit of a tie between CANDU and wind.

Q Why the radical change?

A Capital cost estimates have changed, whereas New Brunswick didn't make any change in their quoted firm power costs, which makes me a little suspicious. Just as soon as they start experiencing the high Le Preau capital costs, then there will be a higher escalation in the capacity charges for their firm power. I really don't believe too much in this second row of figures myself. The change in the wood fired plant was because they badly wanted to change the capital costs to make them higher. You would have to heavily subsidize the cost of gathering the wood for the wood-fired to be economically competitive generation. It doesn't make much sense. There is a lot of thought on Prince Edward Island to developing an island resource base to earn dollars. The only on-island resource that makes any sense is the wind. Cost benefit figures do not tell you all you really need to know about the effects of these technologies.

Figure 19 (FIGURE NOT AVAILABLE) presents some sample expansion plans for the Prince Edward Island system, adding roughly the same amount of resources each time to the system, then finding out what the effect would be on the rates that customers would have to pay through those expansion plans.

Figure 20 (FIGURE NOT AVAILABLE) shows the expansion plans out of firm purchases, nuclear generation, wind generation and a couple of more plans on wood.

Plan 5 is wood all the way. Plan 6 is the minimum necessary firm purchases. I go over all the resources and compare them with their load. I use the capacity timing criteria that is part of the interconnection agreement with New Brunswick to have a certain amount of capacity relative to their load. There is a minimum that must be installed. All of the other five plans provide more resources than the minimum capacity simply because as the price increases, all of Prince Edward Island's present generation becomes peaking generation with not one bit of it base load generation. They've just got zero base load generation. The only bit they've got that looks anything like baseload generation is their share of the Dalhousie coal/oil fired unit in New Brunswick. Nothing else resembles base load.

Figure 21 (FIGURE NOT AVAILABLE) illustrates a couple of these expansion plans. Plan 1 is nuclear and wind. Plan 2 is all nuclear. Plan 3 half nuclear, half purchase. Plan 4 is all purchase. Plan 5 is wood. Try and remember those. That's how the average price of electricity on P.E.I. changes every year under these different expansion plans.

Q Are you serious - 22.5 cents/kW-h?

A Yes, that's what that says - average price. The residential consumers pay a little more than 7.89 cents/kW-h in 1980. That is not just bus-bar cost, that includes all the other costs on the system but averaged out over all sizes of consumers. That includes all of the costs that go into their cost for power, their distribution costs, administration costs, interest and depreciation.

Q As you're getting up there, what percentage is oil-fired or fossil-fired in those costs? For instance, is all that escalation attributed to scarce oil?

A Along the bottom line here we are taking the 1980 power cost and escalating it at the assumed escalation rate for oil.

FUEL COSTS USED IN WTG/UTILITY ANALYSIS (1985$)

NOVA SCOTIA		NEW BRUNSWICK		SASKATCHEWAN	
	(¢/MBTU)		(¢/MBTU)		(¢/MBTU)
Light Oil	1348	Light Oil	1356	Gas	977 to 1036
Heavy Oil	1061	Heavy Oil	1064 to 1196	Light Oil	1260
Coal (all)	396	Local Coal	249 to 316	Local Coal	56 to 202
Nuclear	40	Imported Coal	396		
		Nuclear	40		

Fuel Escalation Rates			Fuel Escalation Rates	Fuel Escalation Rates		
		(%p.a.)				(%p.a.)
Oil	1985-89	11.2	same as for Nova Scotia	Oil and Gas same as for Nova Scotia		
	1990-94	10.2				
	1995-	9.1				
Coal	1985-89	10.1		Coal	1985-89	9
	1990-94	9.1			1990-94	8
	1995-	8.1			1995-	7
Nuclear	1985-89	9.0				
	1990-94	8.0				
	1995-	7.0				

Q From the National Energy Plan (NEP)?

A Roughly speaking, yes. Except where it crosses over and goes to the world price. The world price on oil is assumed to be escalating at 2% in real terms above the general inflation rate. These are the numbers you wanted to have a look at I'm sure. These were roughly 1981 type estimates of increase. I think people would have lowered it a touch since 1981.

Q When I'm looking at 48 cents there, there's an inflation rate. Try to relate that to today?

A 1995 down to about 1980 is about 4%. That will give you an idea. There is the general escalation rate, I put that in so you can see what that was. That answers your question on the second to last row. Most of it is inflation, that's what you are saying, but that's what the whole name of the game is.

Q You are saying that the cost of fuel is doubling with the rate of inflation? Will we be able to afford to drive a car?

A That's right. Unless the car uses half the amount of gas it uses now. A child born today maybe won't be able to get a licence. Consider the car that I have at home. It has got a 454 cu. in. engine, but I've got five kids and require a large vehicle, otherwise, you need two cars to carry them around. The next car I'll own or buy will have petrol consumption cut in half. Thus it will cost me the same amount to run. Now, remember plan 1 was nuclear and wind.

Q Plan 1 is the only one with wind in it?

A Yes. The nuclear and wind option.

Q A toss up is it then?

A Yes, it is a toss up with nuclear. You have to look quite closely at what happens after the year 2000. Up to that time we are increasing rather drastically the amount of generating capacity on that system. We are not just matching the load growth with a little bit more generating capacity, but trying to re-vamp the whole system by installing enough base load capacity. Consequently, it is well over capacity at that stage.

Q But plan 6 is "don't bother with base load," buy the whole works from New Brunswick?

A Plan 6 is buy the minimum you have to buy. Plan 5 is buy as much as makes sense from New Brunswick.

In figure 22 (FIGURE NOT AVAILABLE) it starts to emerge by the year 2000 that you have lower costs if you follow some other alternative. By that stage they are only 20% less. Remember that your wind generation was only installed in 1997. It has not gotten onto that part of its lifetime where it will save you a bundle, but it is not costing you a lot. It is costing you about 1.2 cents at this point...(?)

Q Remind me again of when the first wind installation would be made?

A 1997. Quite. Some in 1988 but 50% more than that taking place in 1997. You will have 57 MW of wind capacity but it is only 3 years old at that date.

Q So there is substantial increment in wind beginning in 1988?

A Yes. That's why Plan 2 in 1995 is a little better, because you are pushing at that time. There is not much to pick between them by 1995 even so. Whereas one has gone for up to 1995. Plan 2 has got nuclear, 30 MW and firm purchase 30 MW. Plan 1 has got 30 MW of nuclear and 38 MW of wind.

Q ....

A Yes, this is what I'm saying. After you get by the first few years with the wind. The nuclear generation that has been installed at roughly the same time is going to be escalating slowly and the wind less slowly in its costs.

Q What about the decommissioning costs of the nuclear power plant?

A Yes. Possibly the decommissioning cost. If you did the analysis today, you'd probably have quite a bit higher decommissioning cost. We are following roughly speaking what Ontario Hydro is doing with their decommissioning costs. In the last rate hearing during this past summer they did push them up a bit.

Q What are they?

A Its about 1 mill/kW-hr at the present moment in this study 1982 dollars.

Q In this figure the wood alternative is fairly cost competitive, whereas you had said earlier wood was out of the question at some point. Is that cost competitive with, for example, half nuclear and half purchase or all purchase?

A Yes. It is quite competitive at that point with all purchase. What can happen is that New Brunswick's costs are not going to rise quite as rapidly as here.

Q What was the rough escalator...(?) to go into this?

A That scenario there is 2%, something like that.

Q 2% per year for...view of speculative things its quite substantial growth...looking almost at negative growth?

A We are still looking at slightly positive growth. And I think that's about 2%.

Q Is that a population growth as well?

A This 2% includes the population growth. The actual use per household of that 2% one is very small. It is mostly population growth, the increase in number of households as the number of kids per household goes down. The population built into it is Statistics Canada's projection from 1976.

Q Wind has quite an advantage compared to nuclear because you can put up smaller units and tailor your supply to your requirements more adequately than with nuclear generatation. You can't build a 1/4 of a nuclear power plant and scale up. They have to be very large.

A That's right. But in these analyses so as not to give the wind that sort of an advantage, we installed wind machines in lumps. We have treated the wind roughly the way we treat everything else. Wind was given absolutely no advantages. In fact its got a couple of disadvantages. In the wind sites we used hourly average wind speeds. If you were to use minute by minute windspeed you would get more energy.

Q Are they looking seriously at the results?

A With their cooperation, I wouldn't say its done for them. People are looking relatively seriously at the results.

I add a few motherhood words at the bottom here, a few warnings. These larger WECS still have to be developed. Even Hamilton Standard doesn't have its machine. We want to go from DAF's .5 MW up to about 4 MW. It is a jump. Work is being done on them.

To achieve this sort of economic viability, the price estimates for these machines have to come reasonably true and the utilities have to be able to buy these machines not at the present high price but at production price. But that is not impossible.

Chalk River was a hellish cost and so was Douglas Point. We got it down when we built Pickering. The utilities also have to have confidence that these machines will have service lives comparable with other assets and performance that is good. We have to get the type of performance out of them that the DAF people are in fact looking at.

Figure 16 lists the WECS as a significant generation option for a number of the provinces in Canada.

To finish up, it was very satisfying for me to do these studies. It was even more satisfying that I was able to do them with a tool, the PROMOD III model, which is used by so many utilities:

- for planning their system
- for evaluating the conventional resources that they currently install on their system

and - for determining what their rate levels will be.

We could do it the same way with wind and get results that are reasonably convincing. It was well worth the trouble, putting the data for the wind machines into the form suitable for running in the power system model to get an accurate representation.

Q What is the scale of the program. What do you run this on?

A It is running on a variety of machines. It is running on IBM 3032's. That big. The smallest machine it can run on is about a PRIME 450. It has got about 100,000 instructions in it. It runs segmented. It can handle any number of generation sources. There is a whole variety of options including a PURPA module to produce things like avoided costs. This is very worthwhile mentioning in this context. A lot of utilities are using it in the States. They are using it for their negotiations with wind power producers.

Q (inaudible).......

A I'm not a meteorologist. My job is to evaluate the worth of things to the power system, given a site, given a machine and given a system.

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BALANCED STRESS VERTICAL AXIS WIND TURBINE

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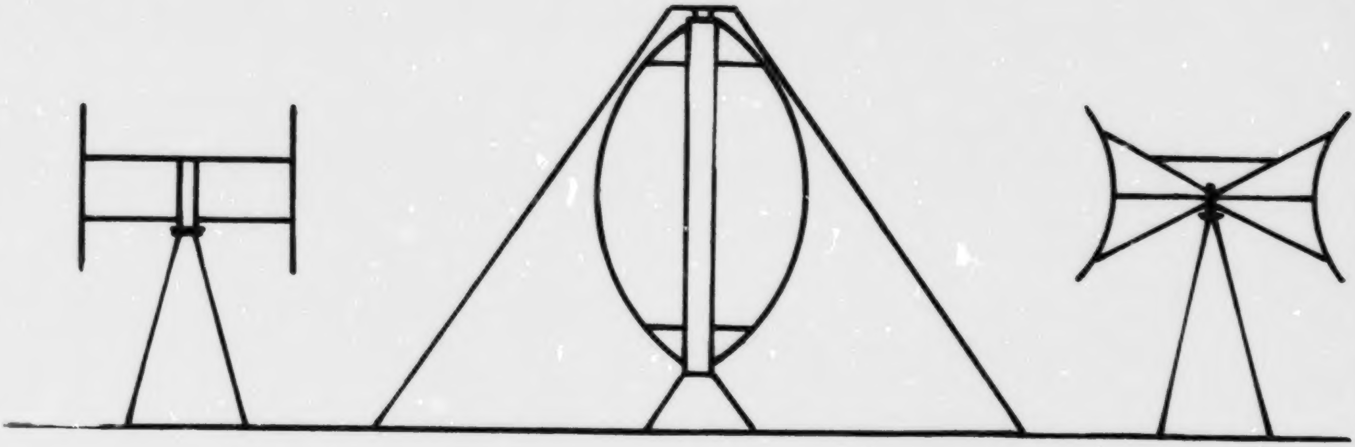
The Balanced Stress Vertical Axis Wind Turbine (patents pending) minimizes bearing size, negates the need for guy wires, eliminates the torque tube and keeps airfoil stress within manageable limits when compared with other vertical axis wind turbines (VAWT).

The Darrieus VAWT employing a troposkien shaped airfoil requires a large torque tube, guy wires, large bearings and a very long airfoil section. The straight bladed VAWT requires a torque tube, large bearings and exhibits high airfoil stress.

The Balanced Stress VAWT employs airfoils that are curved outward and are radially disposed from their axis of rotation or shaft. Arms are employed to connect the airfoils to the shaft, upon which they converge to virtually a common point.

BALANCED STRESS
VERTICAL AXIS WIND TURBINE

Equivalent Power
VAWT



TYPE	STRAIGHT BLADE	DARRIEUS	BALANCED STRESS
Blade Stress	Hi	Lo	Lo
Guy Wires	No	Yes	No
Torque Tube	Yes	Yes	No
Tower	Average	Small	Average
Bearings	Large	Large	Small
Blades	Average	Large	Average
Struts	Yes	Few	Yes

Centrifugal forces cause the centre of the airfoil to be forced outward. This action results in the airfoil tending to straighten and eventually buckle outward. The pull on the arms due to the centrifugal forces set up within itself and the airfoil to which they are connected, has a vertical force component. This vertical component reacts against the airfoil's tendency to straighten out.

There is also a moment at the ends of the airfoils, between the point of connection of the arms and the airfoils' tips. This moment tends to buckle the airfoil inward. It is small and can be reduced to almost zero.

The curvature of the airfoil, the point of connection of the arms and their angle with respect to the horizontal, must be taken into account to achieve a balance condition. The weight per unit length of both the arms and the airfoil can affect the curvature of the airfoil.

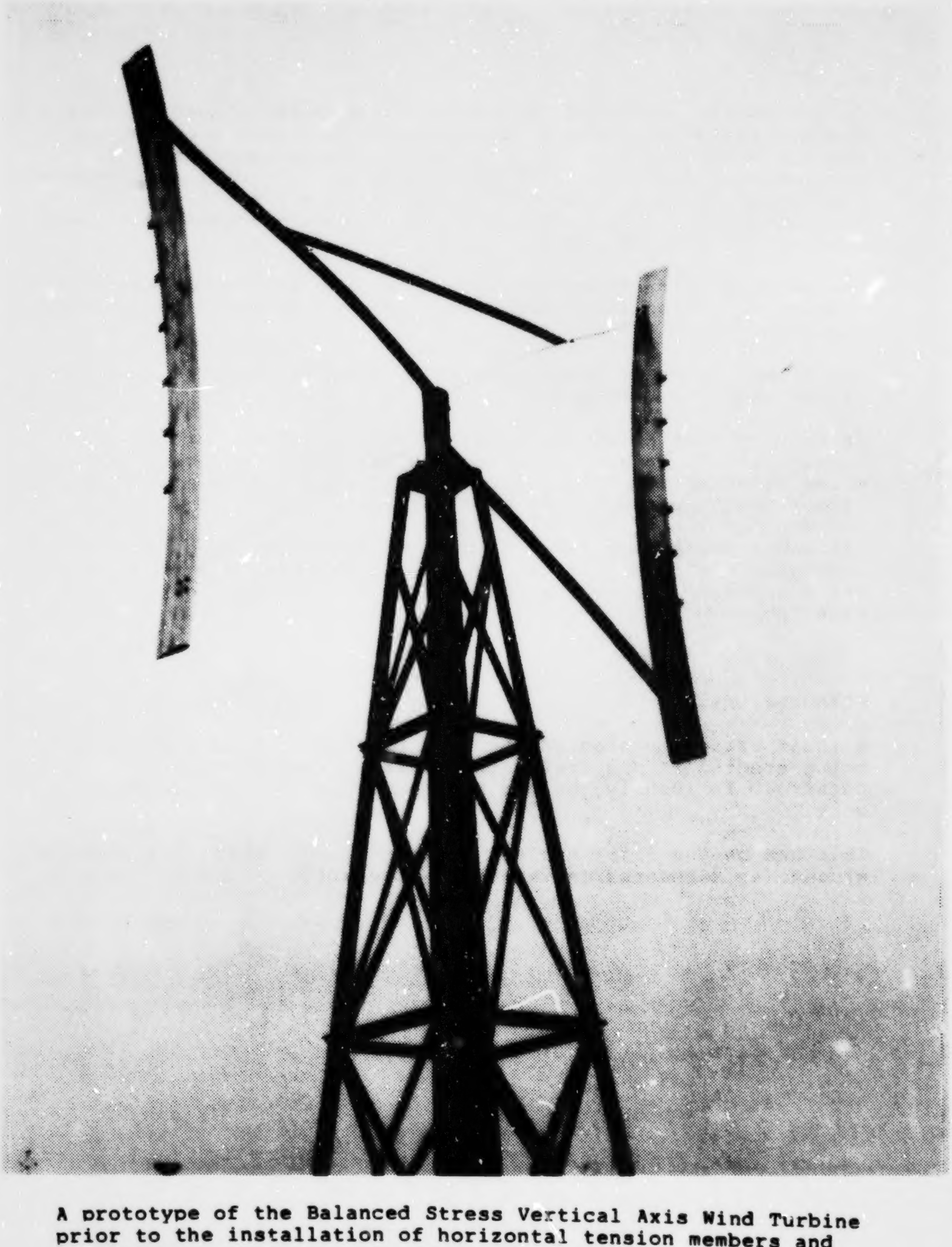
The curvature is set to provide a net outward buckling force which can be counteracted by a horizontal tension member. This compensates for variations in forces on the airfoils due to cyclic aerodynamic forces.

As a consequence of the balance of forces set up within the airfoil, stresses are minimized. Stresses can be made considerably less than those occurring in a straight bladed vertical axis wind turbine. In the straight bladed turbine, compound curvatures occur, when it is rotating, producing premature blade fatigue.

In the case of the Darrieus turbine the airfoils are in tension when it is in rotation, since it is shaped in the form of a troposkien. Both the Darrieus and the balanced stress wind turbine exhibit less airfoil stress than the straight bladed turbine.

In the parked condition, the straight bladed and the Darrieus turbines' up-wind airfoils try to buckle. In this case the airfoils of both turbines tend to take up compound curvatures. Since the wind is quite often very high when the machines are parked, airfoil stresses can become a major concern.

In the case of the balanced stress turbine the up-wind airfoil will tend to buckle inward when parked. It will not go into a compound curvature. The arms of the turbine, however, must be constructed to withstand compression, which is also true of the straight bladed type. In the Darrieus turbine the struts are relatively small and also have to be designed for compression.



A prototype of the Balanced Stress Vertical Axis Wind Turbine prior to the installation of horizontal tension members and furlings.

In the parked, downwind condition the straight bladed turbine's airfoil again will have a compound curvature and the Darrieus turbine's airfoil will be in tension. The balanced stress turbine's airfoil will tend to straighten. It will be prevented from doing so by the vertical force component set up in the interconnecting arms. The horizontal tension member will react against the pull of the airfoil.

The balanced stress turbine will have less airfoil stress in the high-wind, parked mode than either of the other two types of wind turbines.

One other important consideration is that it requires less real estate than the Darrieus.

It is very cost effective since it eliminates guy wires and torque tubes. It also requires smaller bearings due to the elimination of the torque tube and guy wires. The economics favour the Balanced Stress wind turbine.

Its application is similar to that of the other types of vertical axis wind turbines. It can be used to generate electricity, drive a diesel electric system, power a heat churn or run a water pump.

ACKNOWLEDGEMENTS:

A three bladed version of the Balanced Stress Wind Turbine is being erected at Sid Trathen's Welding in Belle Fountain, Ontario. Incidently, he has been extremely helpful in this work.

This has been a joint project between my son, Philip, a physics student at MacMaster University and myself.

THE KORTRIGHT CENTRE'S CONSERVATION AND RENEWABLE ENERGY PROGRAM

Paul Leitch, KORTRIGHT CONSERVATION CENTRE

The Kortright Centre is an interpretive and educational centre within the Metro Toronto and Region Conservation Authority (MTRCA). Their mandate is to educate and interpret for the general public, our renewable natural resources. The reason they got started was mostly for flood control because of Hurricane Hazel. If you are driving up the Don Valley Parkway or Bluffer's Park on the Lakeshore, note all the projects on dams and river banks, that is MTRCA's job. Their mandate is to illustrate the wise use and management of our natural resources. They chose to take up renewable energy as one of those themes and I'm co-ordinating that theme at the Kortright Centre. Not only are we going to be involved with wind but we are also involved with hydroelectricity, wood energy, conservation and solar energy.

The wind area is the first active component of the Kortright Centre. The reason for that is we are putting up a windmill at the Kortright Centre which is being funded by the Ontario Ministry of Energy. Bill Stewart mentioned it earlier this morning.

It is a horizontal axis machine made by Jerry Ball from Wellington Wind. It is a NACA 6415 profile, 3-blade design, approximately 28 feet in diameter. A sixty foot 12" diameter hinged pole tower supports the 17.5 kW permanent magnet A.C. alternator.

FIGURE 1 is a sketch of the site. The Kortright Centre is south of Major MacKenzie Drive, and west of Pine Valley Drive. As you come into the Kortright Centre there is a parking lot with the site approximately 300 m. east. There is a row of trees and forest to the south and east with trees about 20 m. high at the top of the crown.

FIGURE 2 is the micro-terrain profile. There are two high spots. There is a big valley, part of the Credit River - Humber River system, oriented in the North West to South East direction. This is really convenient because the energy 'wind rose' shows most of the energy coming from the North West. While we have not got the on-site monitoring data yet, I believe that this will act like a venturi and increase the wind speed through the micro-topography.

The windmill will be set at the location noted in figures 1 and 2. A battery house which holds all the instrumentation is finished. This is a well insulated, earth-bermed building about 14 feet by 16 feet. It utilizes passive solar gain for heat and has coniferous trees to the north to deflect cold winds. The tower will be guyed with four 5/8 inch wires. We had a girder type tower originally, but decided with Malcolm Lodge at AWTS to go with the pole tower because there are a lot of pole towers

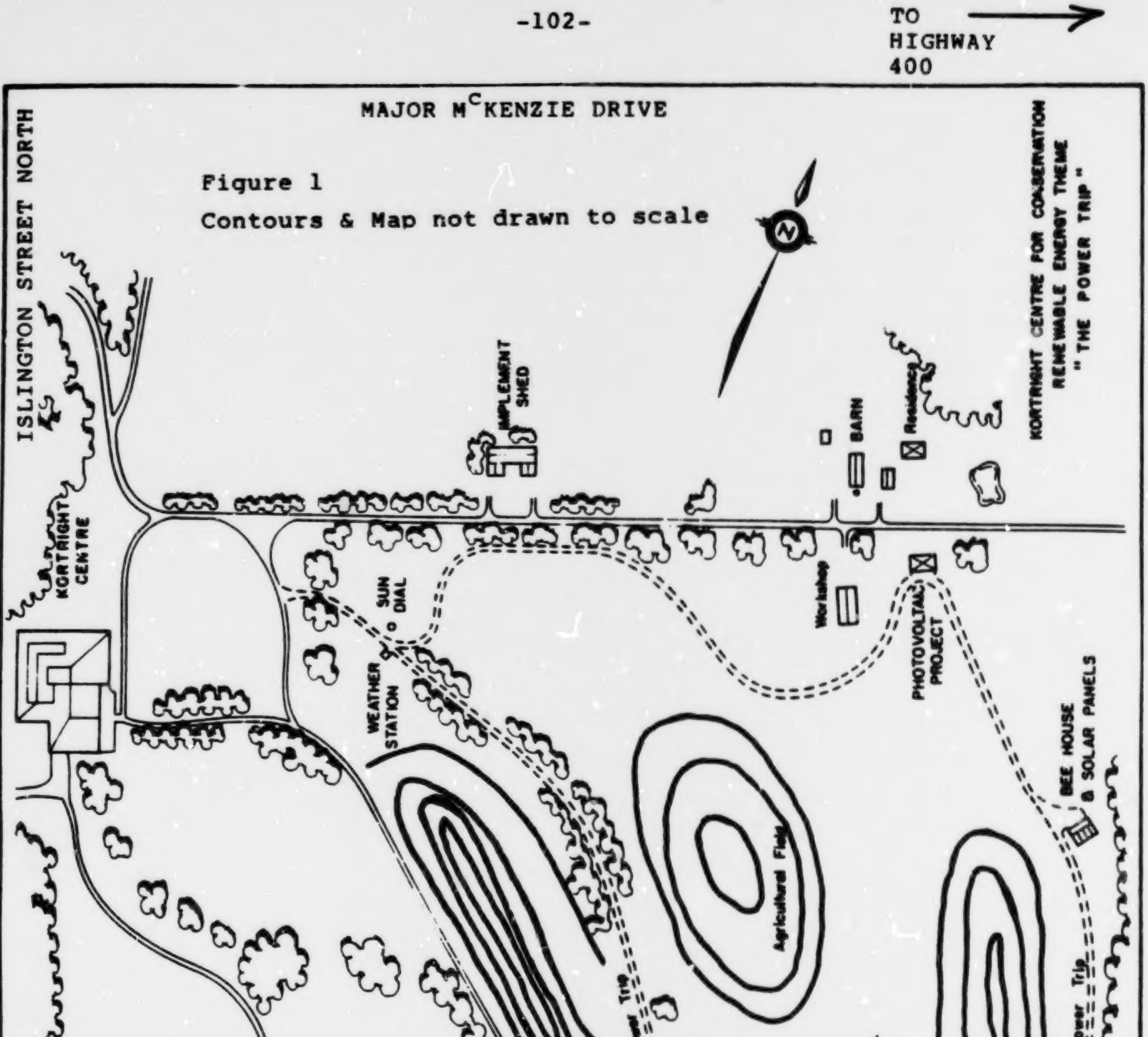

TO HIGHWAY 400
MAJOR M^{C}KENZIE DRIVE
ISLINGTON STREET NORTH
TO WOODBRIDGE
RUTHERFORD ROAD
KORTRIGHT CENTRE
IMPLEMENT SHED
BARN
Residence
Workshop
SUN DIAL
WEATHER STATION
PHOTOVOLTAIC PROJECT
BEE HOUSE & SOLAR PANELS
Agricultural Field
The Power Trip
10 kw HAWT WINDMILL
DARRIEUS WINDMILL
BATTERY HOUSE
POND
SOLAR COOKER
The Power Trip
Gatehouse
N
KORTRIGHT CENTRE FOR CONSERVATION
RENEWABLE ENERGY THEME
" THE POWER TRIP "

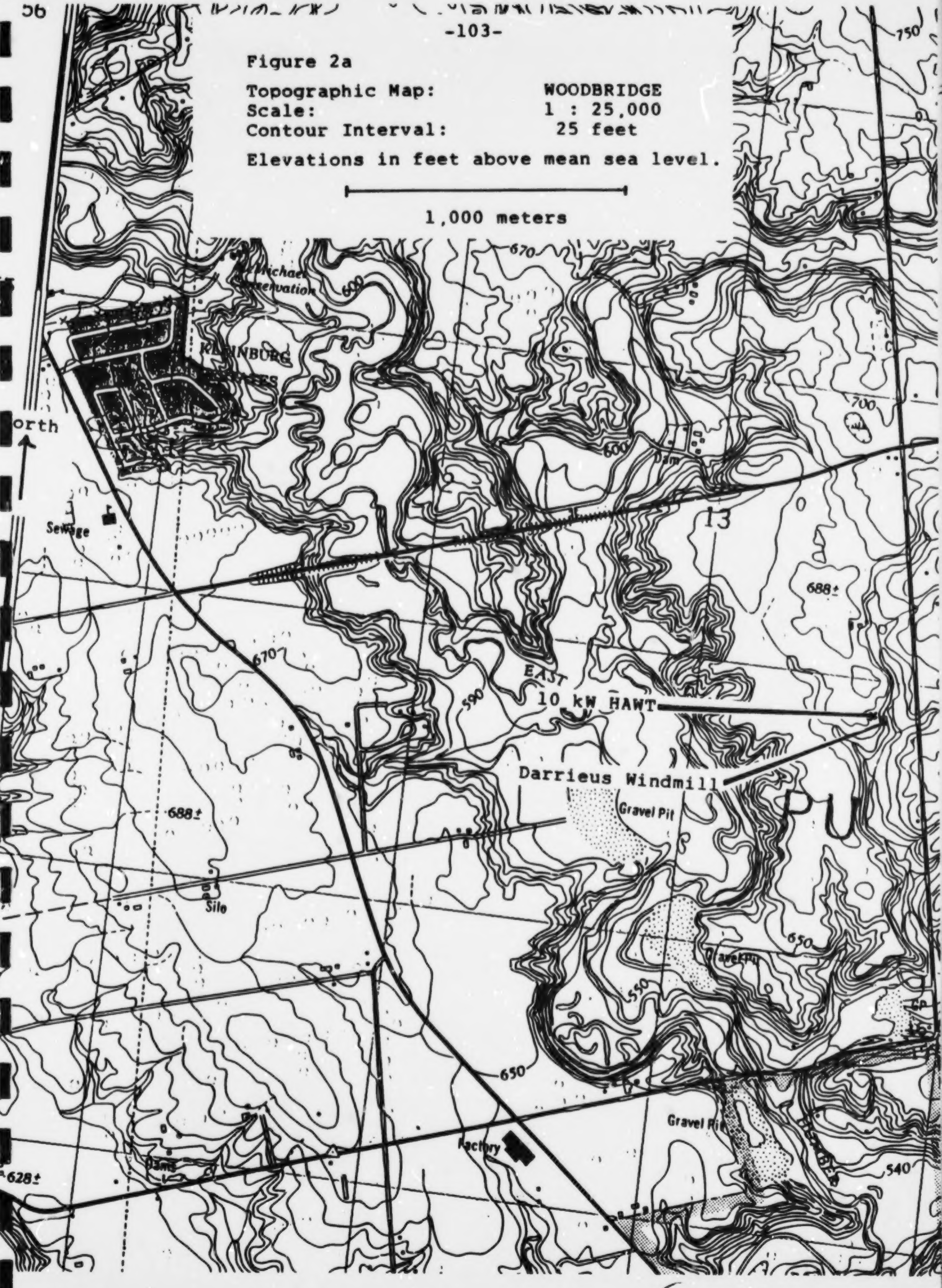
Figure 1

Contours & Map not drawn to scale

Figure 2a

Topographic Map: WOODBRIDGE
Scale: 1 : 25,000
Contour Interval: 25 feet

Elevations in feet above mean sea level.


1,000 meters
North
10 kW HAWT
Darrieus Windmill
EAST
Michael
Conservation
KLEINBURG
ESTATES
Sewage
Silo
Gravel Pit
Factory
Dam
Dams
13
688±
628±
670
600
590
650
550
540
700
750

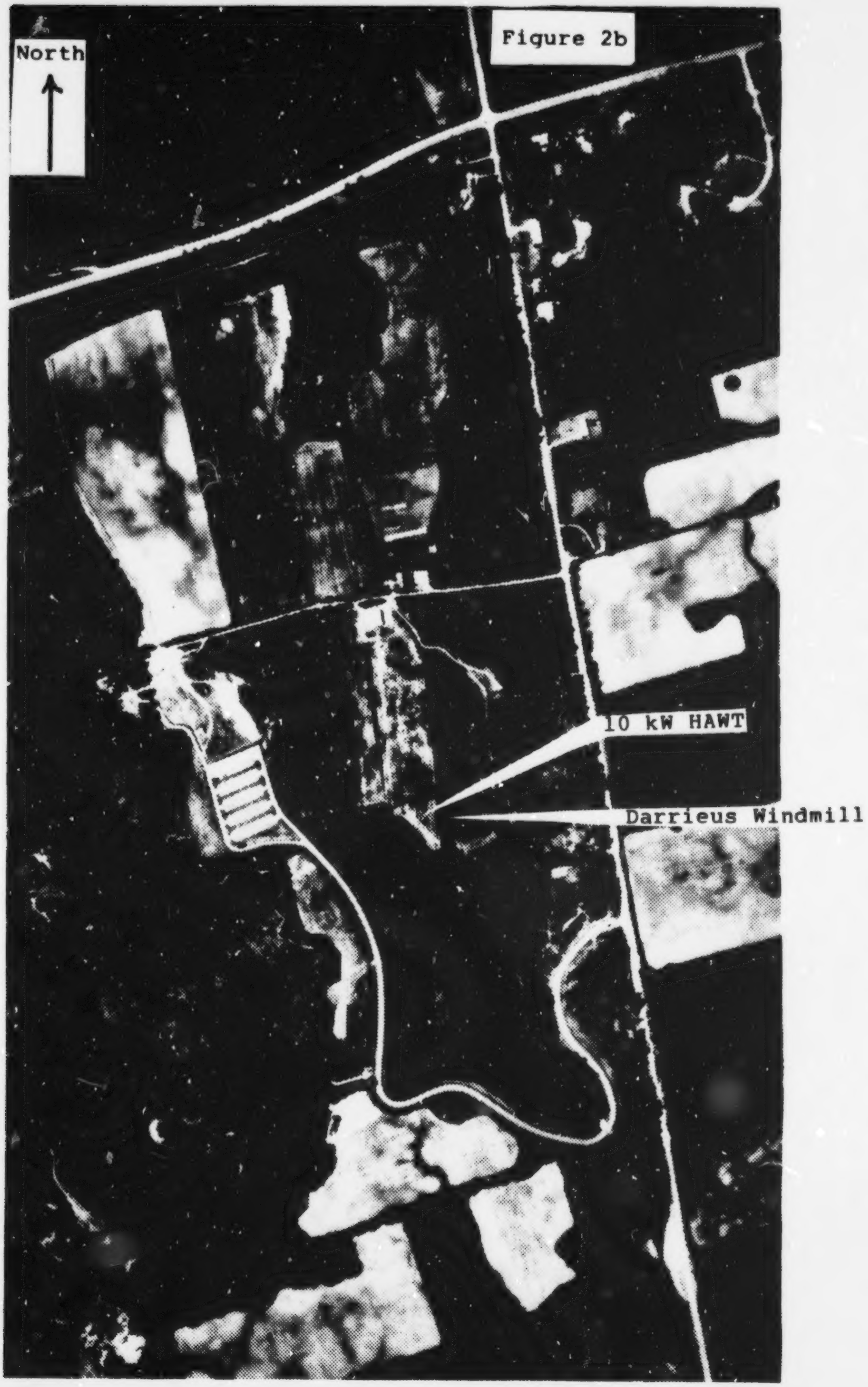
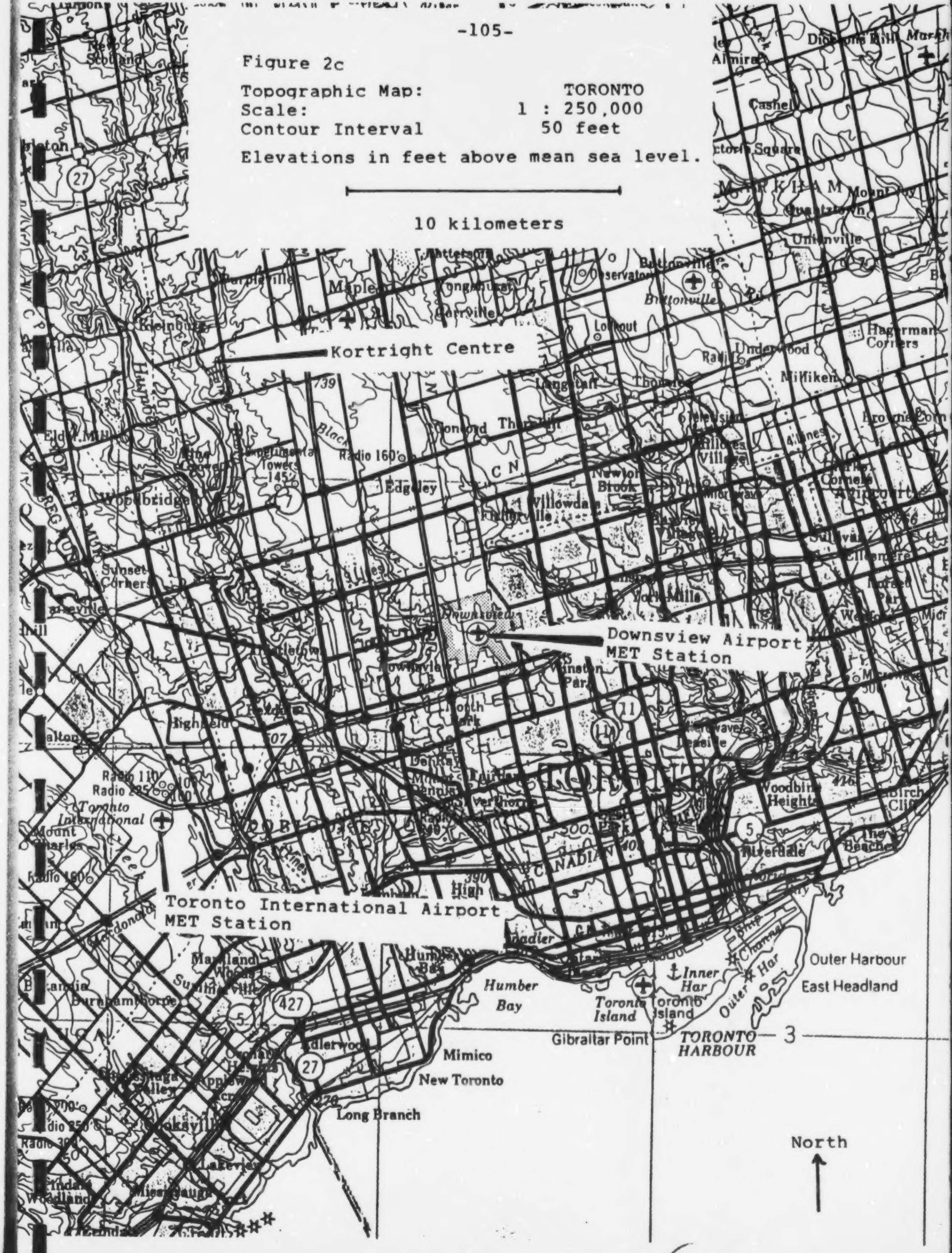


Figure 2b
North
10 kW HAWT
Darrieus Windmill

Figure 2c

Topographic Map: TORONTO
Scale: 1 : 250,000
Contour Interval 50 feet
Elevations in feet above mean sea level.


10 kilometers
Kortright Centre
Downsview Airport
MET Station
Toronto International Airport
MET Station
North
MARKHAM
Unionville
Buttonville
Maple
Kleinburg
Woodbridge
Concord
Thornhill
Edgeley
Willowdale
York Mills
Downsview
Weston
Agincourt
Milliken
Hagerman Corners
Toronto International
Malton
Humber Bay
Mimico
New Toronto
Long Branch
Toronto Island
Gibraltar Point
TORONTO HARBOUR
Inner Har
Outer Harbour
East Headland
Riverdale
The Beaches
Woodbine Heights
Cooksville
Lakeview
Port Credit
Erindale

going up these days and the girder would be too expensive.

FIGURE 3 shows the tower as three 20 foot sections of pipe clamped together. The design, as of 2 days ago, will be a hole cut in the bottom of the pole with a bushing inserted. There is going to be a 28 foot gin pole with a 5:1 pulley system that's connected to the ground at the concrete guy footing. It's a tilt down tower. The pole itself weighs approximately 4000 lbs. and the top unit with blades weighs approximately 1000 lbs. The Kortright Centre purchased a four ton winch and mounted it on the back of a tractor. This is used to raise and lower the mill. The raising/lowering takes about 15 minutes. It is rated at 10 kW in an approximately 22 mph wind. It has a side fan yaw control, the reason being that a tail is too responsive to gusting and, due to gyroscopic loading, damage could be done. The side fan tail keeps the rotor facing into the wind and only responds to macro changes in wind direction.

The first 4 feet of the blade is a boot type wide chord symmetrical blade which accommodates the pipe that holds the blades to the hub. These act as starting cuffs to help start-up in low wind speeds. This mill will start to rotate at roughly 8 mph. It has got really good low speed starting characteristics. The alternator 'kicks-in' around 12 mph, but will 'hold-on' down to 9 mph. We happen to have Weston Road meteorological research station about 3 miles to the south. Using their data we have an average of approximately 9.5 mph. We will be setting up a wind monitoring station manufactured by Pate Instruments on a sixty foot tower near the windmill. The anemometer will be a U2A type. We will have a pretty good idea of windspeed and direction right at the site.

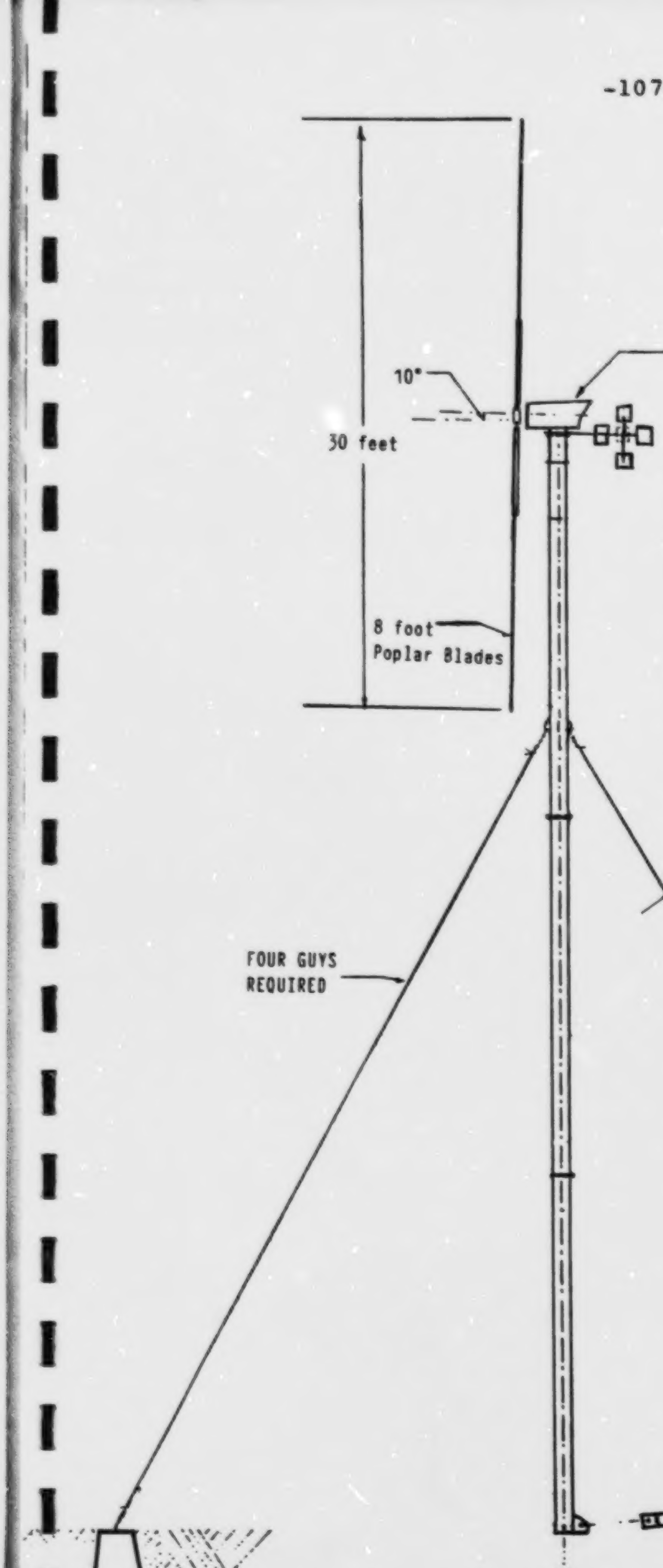
This small amount of research to increase windmill literacy which the public can tour is one aspect which relates to MTRCA ..... We get approximately 60,000 - 80,000 people per year through the Kortright Centre, roughly 33% of which are school kids. It is a great opportunity to let people know what's happening: - "Yes, it is a windmill!". We can bring it down to show them what it looks like.

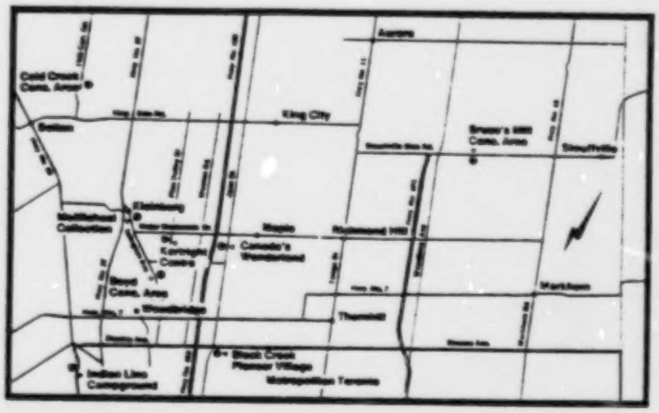
We picked up a smaller 3-bladed horizontal axis windmill on Thursday. It is just 12' to 14' in diameter, maybe 2 kW at 22 mph. This is to show people the two scales. One is much larger, say a farm/co-op scale and the other is a cottage scale. We will be erecting it in the spring. It is also made by Jerry Ball, horizontal axis. We have installed a 12' x 17' (approximately) Darrieus which used to be operated by Ryerson Polytechnical Institute on the roof of the Monetary Times building. This puts us in the unique position of having both a HAWT and VAWT on-site.

Q. What's the centre line of the axis?

A. The 10 kW is 60 feet. We have put the small one in the display area as a static exhibit.

Figure 3


17.5 kW A.C.
P/M ALTERNATGR
10°
30 feet
8 foot
Poplar Blades
FOUR GUYS
REQUIRED


Aurora
King City
Bolton
Cold Creek Cons. Area
Bruce's Mill Cons. Area
Stouffville
Kleinburg
Kortright Centre
Canada's Wonderland
Maple
Richmond Hill
Boyd Cons. Area
Woodbridge
Markham
Thornhill
Black Creek Pioneer Village
Indian Line Campground
Metropolitan Toronto

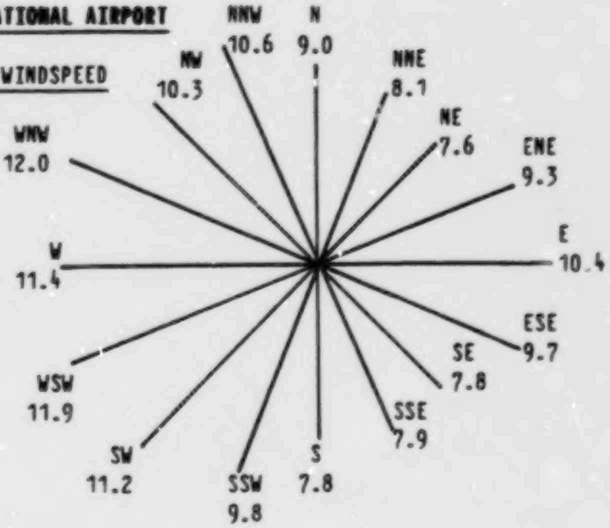
KORTRIGHT CENTRE FOR CONSERVATION - exit from Hwy #400, west on Major Mackenzie, drive 3 km to Pine Valley Drive, turn south 1 km

OPEN DAILY 10:00 a.m. to 4:00 p.m. (Closed Christmas Day)

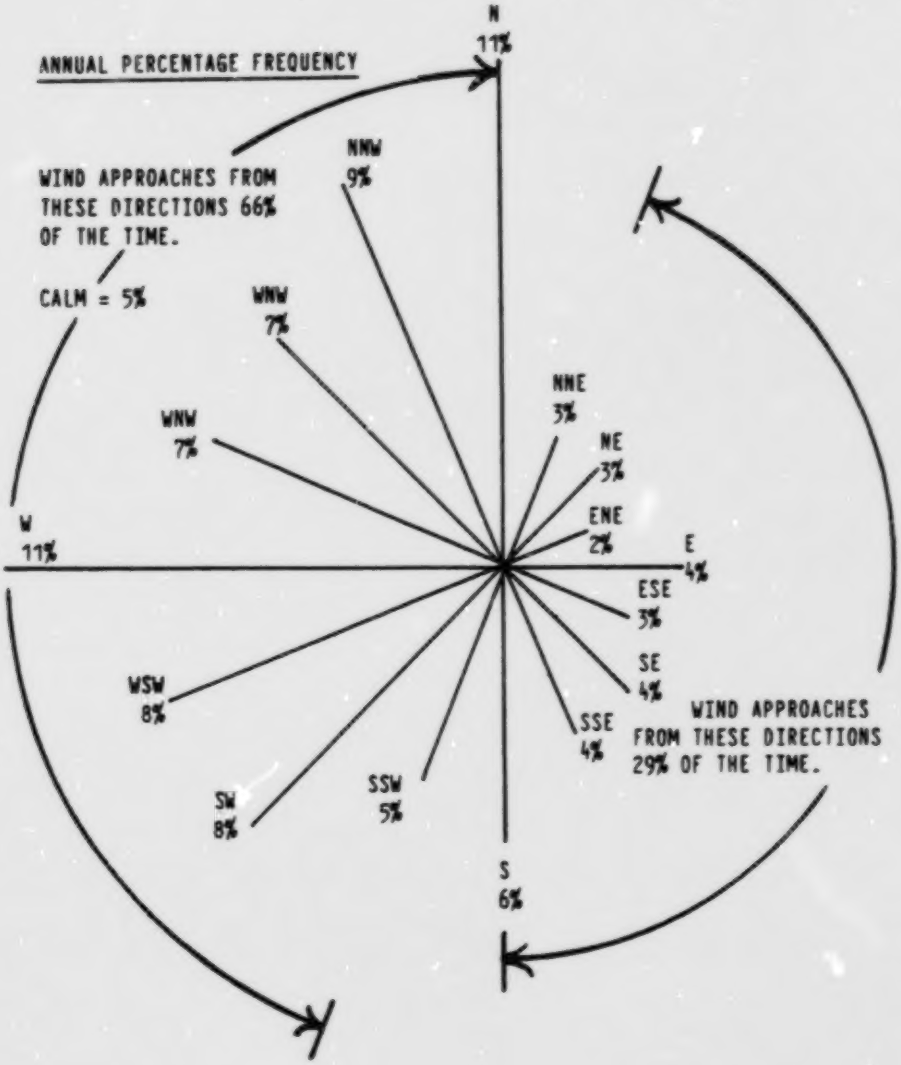
TORONTO INTERNATIONAL AIRPORT

ANNUAL AVERAGE WINDSPEED IN MPH

ANNUAL MEAN = 9.6 MPH



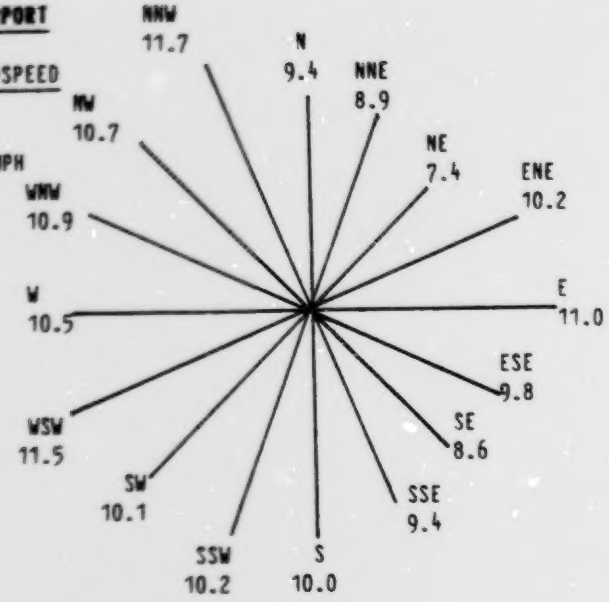
ANNUAL PERCENTAGE FREQUENCY



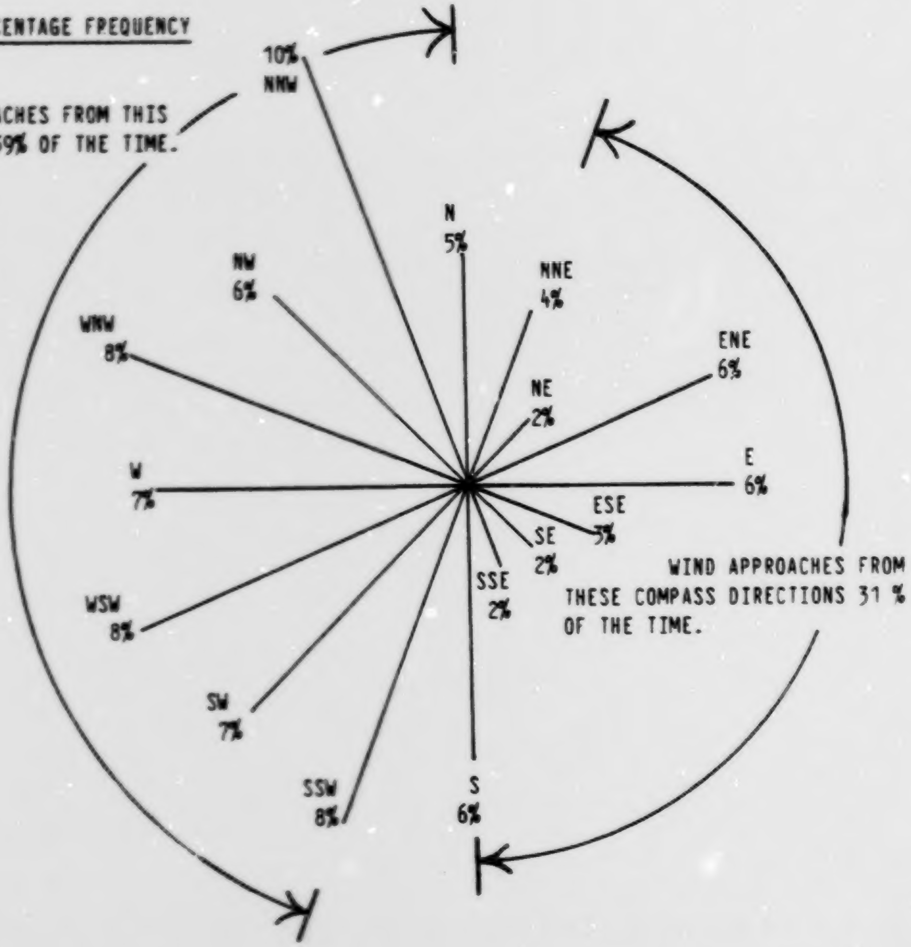
DOWNSVIEW AIRPORT

ANNUAL AVERAGE WINDSPEED IN MPH

ANNUAL MEAN = 9.5 MPH



ANNUAL PERCENTAGE FREQUENCY



WIND APPROACHES FROM THIS DIRECTION 59% OF THE TIME.

CALM = 10%

WIND APPROACHES FROM THESE COMPASS DIRECTIONS 31 % OF THE TIME.

TORONTO (DOWNSVIEW A), ONT.

PERIOD 1958-65 PÉRIODE

HEIGHT OF ANEMOMETER 35' HAUTEUR DE L'ANÉMOMÈTRE

PERCENTAGE FREQUENCY	JAN JANV	FEB FÉV	MAR MARS	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEP SEPT	OCT OCT	NOV NOV	DEC DEC	YEAR ANNUEL	FRÉQUENCE EN %
N	4	5	5	5	5	6	5	5	5	5	5	4	5	N
NNE	4	4	5	3	2	3	3	4	5	3	2	4	4	NNE
NE	3	3	4	2	2	2	2	2	3	2	3	3	2	NE
ENE	7	7	9	7	6	4	4	3	5	7	5	5	6	ENE
E	3	4	9	13	9	4	5	4	5	6	5	4	6	E
ESE	2	2	3	4	4	4	3	4	4	3	3	2	3	ESE
SE	1	1	1	2	3	2	3	3	3	2	2	1	2	SE
SSE	1	1	1	2	3	3	4	4	4	2	3	2	2	SSE
S	2	3	3	5	8	9	9	9	8	7	6	4	6	S
SSW	10	8	4	4	7	7	6	8	9	8	10	10	8	SSO
SW	13	9	6	4	5	5	5	6	5	7	9	12	7	SO
WSW	14	10	6	5	6	6	5	6	6	9	12	13	8	OSO
W	7	9	7	7	7	7	6	6	6	8	9	8	7	O
WNW	8	9	8	9	8	8	9	8	7	7	7	6	8	ONO
NW	5	8	8	8	6	7	7	6	5	6	6	4	6	NO
NNW	8	11	14	12	9	11	9	9	9	9	6	8	10	NNO
Calm	8	6	7	8	10	12	15	13	11	9	9	10	10	Calme

AVERAGE WIND SPEED IN MILES PER HOUR	JAN JANV	FEB FÉV	MAR MARS	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEP SEPT	OCT OCT	NOV NOV	DEC DEC	YEAR ANNUEL	VITESSE MOYENNE DES VENTS EN MILLES/HEURE
N	10.6	10.4	9.3	9.6	11.2	9.9	7.5	8.1	8.8	9.1	9.3	9.5	9.4	N
NNE	9.9	9.8	9.2	9.5	9.3	8.5	6.8	7.4	9.7	8.5	8.7	9.5	8.9	NNE
NE	8.3	8.5	8.9	7.4	6.3	6.2	5.8	6.4	7.2	6.8	8.2	9.2	7.4	NE
ENE	12.3	14.2	11.9	11.5	9.6	8.1	8.6	7.4	8.2	9.4	9.8	10.8	10.2	ENE
E	13.4	14.1	14.8	12.8	10.3	9.3	9.3	9.2	8.5	10.0	10.5	9.2	11.0	E
ESE	11.0	13.0	11.8	10.5	9.1	8.5	9.0	8.3	7.7	9.1	10.3	9.7	9.8	ESE
SE	8.9	10.5	9.3	8.7	8.0	7.6	8.3	8.1	8.0	9.0	7.7	9.2	8.6	SE
SSE	9.0	9.3	9.0	10.8	9.1	9.3	9.1	9.2	9.2	9.8	9.2	9.8	9.4	SSE
S	10.1	10.1	9.3	10.6	10.4	10.0	10.0	9.5	10.7	9.8	10.3	9.5	10.0	S
SSW	11.1	11.2	10.9	10.3	9.8	9.3	8.9	8.4	9.8	9.7	11.4	11.0	10.2	SSO
SW	12.2	10.7	12.5	10.9	9.9	8.6	8.6	8.4	8.9	9.1	11.0	10.5	10.1	SO
WSW	13.7	13.0	12.4	11.8	12.4	11.0	8.4	8.8	9.6	10.5	13.2	12.9	11.5	OSO
W	11.3	11.5	11.3	11.5	10.8	9.8	8.6	8.4	10.1	9.6	11.3	11.5	10.5	O
WNW	13.0	12.2	11.7	12.4	11.3	10.7	10.2	9.2	9.1	9.9	11.5	11.0	10.9	ONO
NW	12.0	12.2	11.4	11.7	10.1	11.2	9.9	9.5	8.5	10.1	10.7	10.6	10.7	NO
NNW	13.4	13.3	12.5	12.1	12.1	10.6	10.0	9.4	10.5	11.5	13.1	12.1	11.7	NNO
All Directions	11.0	11.2	10.8	10.5	9.4	8.6	7.7	7.6	8.2	8.9	10.0	9.8	9.5	Toutes directions

Maximum Observed Hourly Speed	50 SW	Vitesse horaire maximale observée
Maximum Observed Gust Speed	90	Vitesse maximale observée des rafales
Probable Maximum Gust for Maximum Hourly Speed	70	Rafale maximale en rapport avec vitesse maximale des vents horaires

STATION INFORMATION

Airport is located 1.5 miles north on Keele Street from MacDonald-Cartier Freeway in the City of Toronto. Generally flat terrain - eddy effect from north through to east due to buildings.

DONNÉES RELATIVES À LA STATION

L'aéroport se trouve à 1½ mille au nord de la rue Keele, à partir de l'autoroute MacDonald-Cartier, dans la ville de Toronto. Le sol est généralement plat, mais les édifices font tourbillonner les vents du nord en direction de l'est.

TORONTO (INT'L A), ONT.

PERIOD 1955-72 PÉRIODE

HEIGHT OF ANEMOMETER 35' HAUTEUR DE L'ANÉMOMÈTRE

PERCENTAGE FREQUENCY	JAN JANV	FEB FÉV	MAR MARS	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEP SEPT	OCT OCT	NOV NOV	DEC DEC	YEAR ANNUEL	FRÉQUENCE EN %
N	12	12	13	11	11	11	11	11	11	10	8	10	11	N
NNE	3	3	4	3	3	3	3	3	3	3	3	4	3	NNE
NE	3	3	4	2	3	2	2	2	3	3	3	4	3	NE
ENE	2	3	4	4	2	1	1	1	2	2	3	4	2	ENE
E	3	4	7	8	5	3	2	3	4	5	4	4	4	E
ESE	2	2	3	4	3	2	2	2	3	4	4	3	3	ESE
SE	2	2	3	6	6	6	5	5	6	6	5	3	4	SE
SSE	2	2	2	4	7	7	6	6	5	5	3	2	4	SSE
S	5	6	4	4	7	8	8	6	7	6	6	6	6	S
SSW	7	5	4	3	3	5	5	4	5	5	5	5	5	SSO
SW	12	8	5	5	7	7	7	8	7	9	9	10	8	SO
WSW	13	8	5	5	6	6	6	7	6	7	11	10	8	OSO
W	11	12	11	10	8	10	10	11	10	10	12	11	11	O
WNW	6	7	9	9	7	7	8	7	6	6	7	6	7	ONO
NW	6	9	8	8	7	7	8	9	7	6	6	6	7	NO
NNW	8	10	10	10	10	9	9	9	9	8	7	8	9	NNO
Calm	3	4	4	4	5	6	7	6	6	5	4	4	5	Calme

AVERAGE WIND SPEED IN MILES PER HOUR	JAN JANV	FEB FÉV	MAR MARS	APR AVR	MAY MAI	JUN JUIN	JUL JUIL	AUG AOUT	SEP SEPT	OCT OCT	NOV NOV	DEC DEC	YEAR ANNUEL	VITESSE MOYENNE DES VENTS EN MILLES/HEURE
N	10.4	10.3	9.8	9.3	9.7	8.7	7.5	7.7	7.8	8.1	8.8	9.7	9.0	N
NNE	8.7	8.9	8.9	8.6	7.7	7.6	6.9	7.3	7.9	7.9	8.1	8.5	8.1	NNE
NE	8.9	8.7	8.7	8.2	6.9	6.1	6.6	7.0	6.2	6.9	7.8	9.2	7.6	NE
ENE	10.9	11.5	11.3	10.4	9.2	8.3	8.2	6.8	7.1	8.6	9.0	10.4	9.3	ENE
E	12.5	12.2	13.1	12.1	9.8	9.0	7.9	8.3	8.5	9.4	9.9	11.9	10.4	E
ESE	11.4	11.2	11.9	10.1	9.1	8.0	7.9	8.1	8.4	9.1	9.8	11.2	9.7	ESE
SE	8.1	7.7	7.3	8.3	7.8	7.5	8.0	7.8	7.6	7.8	7.9	8.2	7.8	SE
SSE	7.7	7.6	7.8	8.5	8.1	7.8	8.4	8.1	7.6	7.5	8.2	7.2	7.9	SSE
S	8.4	8.4	7.5	7.5	7.5	6.8	7.3	7.2	7.7	7.7	9.1	8.4	7.8	S
SSW	10.7	10.5	11.1	10.7	9.5	8.4	8.4	7.9	10.0	9.9	11.0	10.0	9.8	SSO
SW	12.6	11.0	13.2	12.3	11.1	9.6	9.1	9.2	10.5	10.6	13.0	12.3	11.2	SO
WSW	14.9	13.3	13.1	12.7	11.6	10.6	9.1	9.3	9.8	10.8	14.3	13.4	11.9	OSO
W	13.1	13.3	12.8	12.3	11.0	9.9	9.4	8.6	9.3	10.6	13.1	13.0	11.4	O
WNW	13.9	13.2	13.3	14.0	12.6	10.1	10.1	9.7	10.0	11.2	13.1	13.3	12.0	ONO
NW	11.9	13.1	11.4	11.3	10.4	8.6	8.5	8.3	8.8	9.5	11.1	11.1	10.3	NO
NNW	12.1	12.8	11.8	11.6	10.5	9.6	8.1	8.5	9.0	9.7	11.5	11.4	10.6	NNO
All Directions	11.4	11.1	10.9	10.4	9.3	8.3	7.8	7.8	8.2	8.8	10.6	10.7	9.6	Toutes directions

Maximum Observed Hourly Speed	55 SW	Vitesse horaire maximale observée
Maximum Observed Gust Speed	84	Vitesse maximale observée des rafales
Probable Maximum Gust for Maximum Hourly Speed	77	Rafale maximale en rapport avec vitesse maximale des vents horaires

STATION INFORMATION

Station is located on the slightly rolling to flat terrain. Nearby to the west is a small valley containing the Etobicoke Creek. Most of surrounding countryside is open on which occasional trees are found. The shore of Lake Ontario is about 8 miles southeast and main metropolitan area is several miles east.

DONNÉES RELATIVES À LA STATION

La station se trouve sur un terrain plat ou légèrement accidenté. A l'ouest, tout près, un vallon conduit à Etobicoke Creek. La majeure partie de la région environnante est dégagée et ne porte que quelques arbres. La rive du lac Ontario commence à 8 milles au sud-est et le coeur de la ville, à plusieurs milles à l'est.

Q. Pole diameter?

A. Twelve inches. We tried to get a 1/4" thick pipe. Canron does not make 1/4" pipe because it not a big demand item. As a result we are using almost 1/3" which is a hefty pipe. I think we are OK force-wise and stress-wise with 1/4" pipe, but the closest we could get was 1/3".

That is the wind aspect of it. We will be feeding into eighteen 6 volt Varta batteries, charging them up. Any excess energy will be dumped through 6 x 1.5 kW baseboard heaters. This is what we will do with the load for the first year. The agreement with the Ministry of Energy is to monitor the energy ouput compared to the energy that is available in the wind over a full year. After that we have to decide what we are going to do with the energy. I'll talk a little bit about our thoughts on that in a second.

The generator is a 3 phase, A.C., multivolt, self-exciting alternator type rated at 17.5 kW. It is wired for 110 volts, 3 phase. It starts turning at 8 mph. It starts charging at 18 mph and, through a mechanical pitching mechanism, will pitch out to stall around 28-32 mph. We still have to adjust the T.S.R. for optimum output and operation.

The reason this site was chosen was because it is an excellent wind site. There is farmer's field to the north, approximately 10 acres. These trees here are not very tall and this distance to the east forest is probably 600 feet. The rule-of-thumb is 10 times the height of the tree away, so I think we're pretty good as far as siting goes.

This will become the energy site at the Kortright Centre. It also has very good solar access, so we can talk about solar energy and wood as well. As a renewable energy site it is very good.

Regarding what to do with the output power. We are too far from any grid. There is a little gatehouse to the west for collecting ticket money. That distance is 300 meters. This distance to the grid is about twice that and is too far to run cable.

There are two options being considered presently for utilizing the energy.

One is the production of hydrogen using an Atmospheric Environment Service scale hydrogen unit made by The Electrolyser Corporation Limited (i.e. Stuart cells). The Remote Power Group at the Ontario Ministry of Energy is interested in the application of hydrogen as a fuel in remote communities.

The other one that appeals to me, insofar as it is a southern Ontario location, is the production of nitrates from air for fertilizer. There is a company in Michigan called Ni-Electra and they produce nitrate based liquid fertilizer from water and air. Fertilizers presently are produced from natural gas - a non-renewable fuel, so it would be an interesting demonstration if we could make it from water.

Q. How is it made from water?

A. It's an arc principle. You create a plasma which changes water to produce a nitrogen based fertilizer. Don't know much about it, who knows how it works.

You can see the beauty in both those systems. You are producing hydrogen or these nitrates. You can produce these two merchantable commodities 24 hours a day. As long as the wind is blowing you could make a fuel or a fertilizer. Another option is to provide electricity to power a submersible pump. We are building a 1/3 acre pond beside the mill and have dug a 6 inch diameter cased well to 136 feet. This could be operated through an inverter at the well to keep the pond full and fresh.

In the States, Saginaw College is doing a test with a 7.5 kW Jerry Ball windmill producing nitrates. These people have told me that the system works well and provided enough fertilizer for 100 acres of corn for 1982. I think it appropriate because we are remote from any electrical grid which is the real life situation in a remote community.

As an interpretive, educational 'come-and-look-at-me' type application, I'm trying to induce as much monitoring as is feasible. Because it is a big piece of machinery, we should try to get as much use out of it as possible. I've been talking to the electrical engineering department at the University of Toronto and they've expressed interest in doing undergraduate theses on it. It would be great to have that kind of input and for getting data.

One reason we got this little 3-blader, 12' diameter unit is because we are currently working with a couple of people from York University putting together a proposal to construct a lake aerator from the wind. It's nothing new, Bowjon makes them, and there are a couple of other companies that make them. Ours is different in that it maintains the thermal distribution of the lake.

Bowjon's aerator is just to keep a lake from freezing in the hopes that there will be enough oxygen to keep the fish from dying, but this also disturbs the temperature distribution which apparently harms micro-organisms that the fish need.

What we are investigating is another problem with lakes especially in southern Ontario. With so many farms around lakes you get a lot of run-off and eutrophication of the lake where you are killing it with too many nutrients, phosphorous and potassium in particular. A lake flip-flops in temperature every year. In the summertime the top is warm and the bottom is cold while in winter the bottom is warm and the top is cold. The bottom is 4 degrees Celsius while the top, where the ice is, is 0 degrees Celsius. Fish, in particular cold water fish like Muskie, Pike, Pickerel, have trouble surviving this because they need very well oxygenated water, which is not the case for warmer water at the bottom.

Presently we have a 3 Hp air compressor that pumps air into a manifold that floats in the water. It is an old design, figure 4 (not included) illustrates the principle. You have a tube going down with a diffuser and a tube comes up, going to the air compressor. So bubbles come up from the bottom. Because cold water fish don't like warm water, you don't want to mix the temperatures of the water, you want to keep this thermocline level stationary. What this design does is bubble air up. It is a bubble pump, very similar to the bubble pump you see in sewage plants but with a ceramic diffuser part way down. It aerates on the way up without changing the temperature drastically and it forces the water back down again. So the temperature is not disturbed in the lake but the oxygen count is increased dramatically. It eliminates winter kill of fish, which is the problem.

What I suggested is because it is a 3 Hp air compressor, why not mount the windmill and compressor on top of the tower and just feed the air down. Whenever the wind blows you get aeration of the lake. This is the proposal we're thinking of because Don McQueen of York University is on Lake St. George out by Oak Ridges which happens to be on Authority property. The reason we are going horizontal axis is because we want the unit to be self-starting as often as possible. We are thinking of putting in a small compressor, a vacuum pump run in reverse. It would blow approximately 40 cfm air down the tube at about 30 pounds per square inch.

The blades, Wellington Windpower's make, are laminated poplar for both the 17.5 kW machine and the smaller unit. The reason they used Poplar as opposed to Sitka Spruce is because it is really difficult to get clear wood these days without a lot of cost and running around. Poplar apparently is consistently clear and it takes glue very well. It is very strong, and very light.

Q. What speed is your air pump running at?

A. I don't know. We're still trying to find a pump that will do it. Most of the pumps on the market are 1725 rpm. That's a problem for a wind system because we don't want too much gearing. The vacuum pump is a vane type pump with carbon blades so it doesn't need a lot of oiling, which is really handy. One of our underlying principles is to make it so you can put it in a Beaver airplane to fly it anywhere you need it. Drop it off, leave it for 3 years, aerate the lake then come out and retrieve it.

Q. What was the pressure again?

A. To get down below the thermocline you need about 50 feet. So 50/2.3 gives about 25 lbs. Since 25 lbs. will do 50 feet, we use 30 psi to be sure.

Q. Diameter of pipe?

A. About 1 1/4" to 1 1/2". The bubbler pipe is about one meter and these are a bit smaller. The two down pipes' area equals the bubbler pipe's area.

Q. Is there a substantial market for this device, or just one or two?

A. Hard to say. I'm just jumping into it myself. A lot of work happened in Sweden where they have this problem a lot. Utah, Wyoming, and B.C. have done some work. Mountainous states or countries where they get this problem of winter kill. We'll have to address that. A lot of them are around now in Europe. Some are submersible, some are on top of the lake. Don McQueen's system is apparently the best in the world.

Q. How will the windmill stand up in the lake? A swinging tower?

A. It will be a floating tower. We haven't addressed yet how much floatation we'll need. We'll want to keep this as light as possible.

Q. Has to be quite a base?

A. Yes, the present design uses outriggers on all 4 sides which just stay out. An advantage is that it will dump the wind whenever it blows too hard. It will tip back and dump it, eliminating that type of problem. The windmill uses a side fan tail for yaw. It's got to be as maintenance free as possible. This thing will be floating in a lake with an anchor with nobody looking at it for 3 years.

Q. On the 10 kW machine, what is the length of the gin pole?

A. 28 feet approximately, attached at the base hinge so when the tower goes down it comes up. Jerry was telling me the other day that they are connecting it to come back down so you don't have the gin pole stuck up there all the time. Some kind of ratchet mechanism. Four 5/8" guy wires keep the pole upright.

Q. What made you decide on truck batteries for the Kortright Centre?

A. Jerry Ball recommended this based on his experience. They are also not as expensive as the Gould model which are $800 each. I guess not as much as the aircraft or Bell telephone ones.

Jerry runs his machine shop with those batteries. He's got a full machine shop with big lathes. He paid under $200 last year for his total electric bill.

Q. Are these electric forklift truck batteries?

A. No, transport trucks. He's got them sitting in his shop. He's got a bunch of new ones from Bell Telephone that he uses. He has 2 electric trucks and a jeep he runs on wind. Interesting guy.

Q. Isn't ozone created by using an arc for fertilizer production?

A. Yes, it will happen as part of the process.

Q. Isn't ozone considered a threat to the atmosphere?

A. I think the ozone layer of the atmosphere is deteriorating because of NO_x emissions in smog from jets and cars.

Production of O_3 is a lot nicer than the production of

fluorocarbons.

Q. The Electrolyser Corporation Limited gave me the impression that they think that the hydrogen technology that they have is industrial technology and not really marketable to farmsteads, largely because it is corrosive and explosive if not handled properly. Your comments?

A. I was looking at the smallest model they make. For A.E.S. balloons, it comes out compressed for you in a tank. I agree. I don't know if I want to play with hydrogen. It's not as explosive as gasoline. If you breach a cylinder of hydrogen, it goes 'psssss' all over the place, it doesn't blow up. If it does you can fend off the flames with a piece of tin foil.

Q. I saw that TV show too where some marksman was firing on gas and propane bottles. Now the hydrogen one was one of those metal-hydride things. You would not expect an explosion under those conditions, but perhaps a cannister with compressed hydrogen might?

A. It doesn't. What it does is bleed off fairly quickly.

Q. For example, hydrogen production is one of the concerns with CANDU reactors. In a power surge of one sort or another, that explodes and creates water hammers blowing stuff all over the place.

I have an interest in hydrogen too. Hydrogen does not appeal to me in an 'open-loop' process where you produce hydrogen and oxygen then just burn the hydrogen. You need both the oxygen and the hydrogen, to recombine them efficiently in a fuel cell. But fuel cell technology is a little heavy duty for out in the woods. I'm not sure that is the best place for it, especially when you have to fix it. Perhaps it will be most useful for storing large amounts of energy on a utility scale where the same water is continuously circulated through the electrolysis/storage/fuel cell 'closed-loop' process.

Presently what I'm more interested in is straight heat. It is easy enough to deploy, at least in terms of heating elements for, say, a greenhouse or other end-use. For a stand-alone windmill at a great site and conservation centre, why not a greenhouse? They must need flowers or tree seedlings to landscape the park?.

A. It's funny you should say that because it is the energy area and it would be great to put up a greenhouse there with the windmill powering that greenhouse. That would be a better illustration of the technology, what good it is. But there is talk of "that's a pretty hefty investment", $16,000 for a greenhouse. I don't know what the smallest hydrogen unit is, but it is that order of magnitude as well. $16,000 would be a small greenhouse.

Q. I find that hard to believe.

A. I haven't investigated it. Just from talking to a few people.

Q. A greenhouse should only be about $2000 in materials.

A. Its not the materials that kills you, it's the labour.

Q. The other thing is: in terms of doing something for people in remote communities, rather than hydrogen, why not alcohol production? Use the wind energy for process heat, a heat load connected by electric means?

A. Those are good points. I agree, something that will have to be addressed in a year. The more feedback I can get, the better. The first year will be monitoring, after that it will be ours to use as we see fit. The end-uses mentioned are the first two things that popped up. Whatever is most appropriate will be developed.

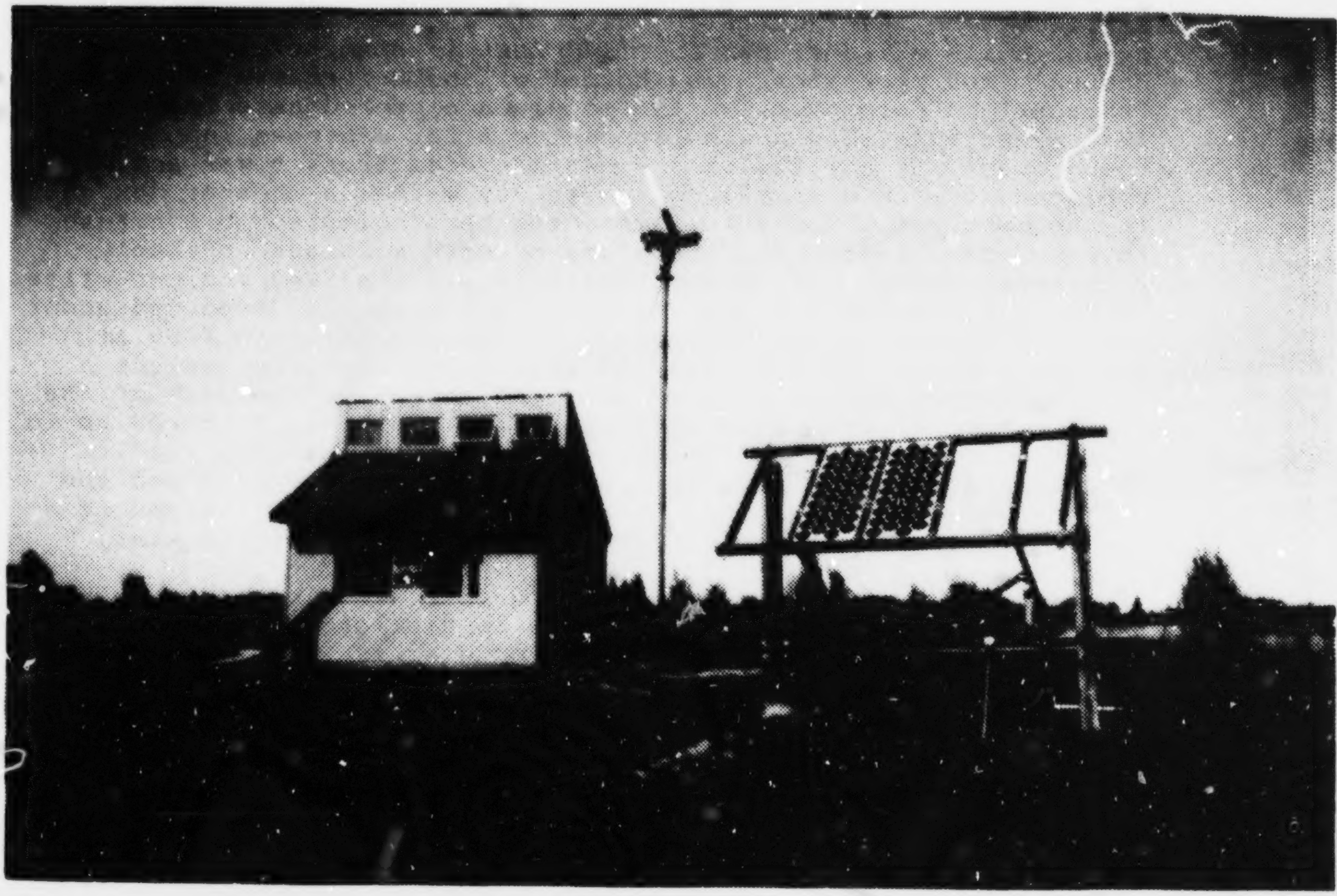
Q. Continuing on this alcohol. If you look into it, there are more regulatory barriers to alcohol production than hydrogen. It is questionable which is the 'softer' energy path. You can see the 'pros and cons' both ways. More social reasons perhaps against alcohol than hydrogen, the social context in which you are talking about a 'total systems' approach. We may no longer be able to support the consumption we once had. In a conservation area you must be managing woodlots, so you could go into methanol production. Ferment that biomass to power the chainsaw and other harvesting equipment that you use to cut trees. Initially as an experiment, but eventually aim to harvest a surplus. For the ethanol production, which may be better for internal combustion engines than methanol, use some kind of biomass other than the wood fiber grown on the property.

A. We have a farmer across the street who grows corn.

Q. Or Jerusalem artichokes?

A. We've got them growing wild all over Ontario. Well I agree. I mentioned that once and you're right there is a thing about methanol or ethanol production. A lot of people say "Where can you use it?" It is the same old thing. It is the matter of convincing people that there are a lot of options to investigate.

Q. There is no problem with using alcohol. Just pour it straight into your gas tank to use as a fuel extender or an octane booster instead of lead. There is no technical mystery about it. Cheaper than lead and safer. You have to weigh the pros and cons of the emissions from alcohol, the flash point for explosions. There is a social thing which also must be considered. Talk to Mart Kirik of the Ontario Ministry of Agriculture in North Bay for 'state of the art' information.



WIND ENERGY OVERVIEW: DEVELOPMENT OF SMALL AND LARGE SCALE TURBINES FOR ELECTRIC POWER GENERATION

David Hoffman,
Renewable Energy News

Wind electric generators have been around for about 100 years now. Twenty to thirty foot diameter units were up in Gedser, Denmark circa 1900, a big propeller and two little ones. The first electric wind generators appeared in the early 1880's, showing the concept of electricity from the wind is almost a century old. For example the 1883 Norwegian polar expedition used a small generator for lights. At the time, New York City was lit by gas. During the 1920's and 30's there was a big spurt in European wind engine building. I don't mean small machines like Jacobs or Winchargers, but machines such as this built on the Orkney Islands, Scotland. This machine was actually built in 1950 by the John Brown Co. for the North of Scotland Hydroelectric Board. Each blade is apparently 50 to 75 feet long and it had a rated output of 100 kW. It ran for a few months then was shut down for operational reasons. Probably the cost of oil dropped.

The big names in Europe in the 20's and 30's were Flettner, Darrieus (who never actually built his egg beater windmill though he did build a two blader about 80 feet in diameter like the NASA Mod 01), and professor Erich Hutter of the University of Stuttgart in Germany. The two machines pictured here from the 1940's and 50's show how he innovated a lot of ideas and techniques. He got rid of the cantilevered truss tower and replaced it with a single pole with guy wires, a cheaper design in the long run. Today the Americans have switched to concrete towers. The blades are fiberglass on both machines, probably with metal cores. Professor Hutter is still alive, you can write to him for specifics. The small one built in 1948 produced about 6 kW, while the larger 34 m diameter one was built in 1956 at Stutten Germany and produces 100 kW. Other features include a small pinwheel device mounted at right angles to the disk of the rotating propeller. This very sensitive pinwheel is hooked up to a worm gear which turns the gondola and rotor into the wind. This is a carry-over from European grain grinding mills and the Germans and Danish use this on small machines today instead of a tail vane to guide the propellor fan into or out of the wind.

Since wind proceeds at a shear over ground, it blows down rather than across. Jacobs recognized this in his most recent 10 kW design where the plane of the rotating disk is tilted back from the vertical to be more flush with the wind front. However, the NASA Mod 01 didn't have a hub that teetered or adjusted while it rotated, so when the U.S. built this first 100 kW machine in the late 1970's (the same size as Hutter's 1956 unit), it ran into vibrational trouble resulting in blade cracking plus noise problems caused by the 'shadow' of the cantilevered tower.

This French machine built at St. Remy des Lyons in 1963 produced a maximum of 1 MW. Everything on the tower weighed 96 tons. However, a leg tore loose in 1964 and was never repaired. Notice smaller machine below and to the left.

This concludes the section of slides on the past development in large machines. Even today with new techniques and materials we are not doing anything terribly new, it's all been done before.

This shot of a machine in Taiwan appears to be a Danish Windmatic import or copy. Note the braces between the blades and the design of the blades and arms, one of their trademarks.

This next unit has two counter-rotating propellors mounted one behind the other. This machine was designed by a Swiss engineer in 1975 and built near the coast at Silt, Germany. The idea behind this 70 kW unit was that the generator armature was rotated by one set of blades while the field coils were rotated in the opposite direction by the other set. (The small Bergy machine at the AWTS rotates the field coil around the fixed armature). The intent was to achieve a greater relative rpm. Unfortunately, it didn't work. One set of blades tended to lock the other set into its direction of rotation (in whichever direction).

Even though I missed the wind energy conference in Oregon this year, here is a view of the Boeing Mod 02. This unit, with a maximum rating of 2.5 MW, is installed in the Goodnoe Hills, Washington State, a few hours N.E. of the Columbia River. It is huge. There are two other machines sited with it at this first windfarm in the world consisting of MW size wind turbines. The main blade is rigid with only the outer tips of the blades feathering to slow it down. Anemometers and wind direction indicators on booms control servo motors to yaw the machine into the wind. I don't know if the upwind operation of this machine creates blade wake interference with these sensors. However, they did have a problem when doing emergency shutdown tests to determine its reliability, its ability to hold up. They let it spin up in high winds to an overspeed condition, then opened the feathering tips quickly to do a fast stop on the machine. Apparently, the servo motors which pumped the feathering hydraulics had 'gritty' fluid in them so hesitated in opening the feathering flaps. Unfortunately, the generator had been disconnected from the load. Without resistance to the free spin it burnt out completely. Presently, they've taken down the rotor and are still looking at. They feel a better oil will solve this problem. (Ray Richards of the AWTS says the unit was putting out 2 MW the day he was there on the tour from the wind conference).

Here is a copy of an advertisement from the 1930's:

"Buy yourself a Philco C32-5K radio and get a free Philco 200 watt wincharger on a 10 foot tower to put on your roof."

This is indicative of the commercial atmosphere at the time with several manufacturers in the U.S. producing home-size, farm-size machinery.

Here is a 2 kW Jacobs-style wind turbine made by Allied Electric of Spencer, Iowa - not unlike the one we saw earlier. Actually, Jacobs bought out that company during the war due to copper allocations and in order to acquire the blade actuated governor.

When someone mentions 'Wincharger', you usually think of the 200 W 2 bladers with the bucket air brakes that fly out in high winds. However, this machine is the larger model 3215, a 32 VDC, 1500 W unit. Just two of the four blades are centrifugally activated by weights to feather their pitch. This design, which put out 10 amps or 850 watts was relatively efficient.

Here is an example of hardware produced by the Sencenbaugh Company in their early days. Its prime feature is its roots in the 'great American tradition' springing from the end of the 60's, i.e. the 'peace movement/back-to-the-land movement/environment movement/alternative and appropriate technology movement'. It's an extremely simple machine, just a generator, propellor, and turntable (only three pieces). It probably did not last that long.

This shot shows another group in the U.S., Windworks, operating their mobile wind tunnel, i.e. a truck driven at various speeds. Perhaps they loaded the machine with the truck's battery to measure the output. They used this rig to evaluate different methods of feathering the blades, note the shaft going through the two bearings here. At some point they probably added weights. Here is an example of what I have described as centrifugal governing. Note the bar with the weight sticking out from the root of the blade. When the blade starts to spin above a certain rpm, the weight starts to throw itself out, away from the centre of rotation, either about a pivot point or along a slider arm as the case may be, which turns the blade and feathers the pitch. The Windworks, Bergy, and Dunlite machines use this principle among others. However, the pitch control mechanism for each of the blades must be coupled or linked together, otherwise get bad vibration problems when the blades don't feather simultaneously.

Here is a close-up view of the Windworks feathering system. Note how it is all connected together through this collar and the arms, with each arm coming to the central shaft to compress the spring. They used the expanded honeycomb blade shape in this early prototype (circa mid-early 1970's).

Note the two belts in the Windworks' generator set-up. One goes from the propellor shaft to a jack shaft then down at the back from the jack shaft to the alternator shaft. Stepping up the rpm twice through these two pulleys achieves a total ratio of 9:1. Plans for this windmill are available from Popular Science. Note the wood tower.

Grumman Energy Systems in the U.S. and Negev University in Israel are exploring the diffuser/augmentor concept. An airfoil shape is closed around in a circle like that illustrated here to create a venturi concentrating/funneling effect. A propellor located in the throat tends to perform in an apparent contradiction to a literal interpretation of the Betz limit for its diameter. However, this contradiction is resolved when you consider the diameter of the diffuser/augmentor rather than the swept area of the propellor.

In the mid 1970's, during the start-up of the small wind/back-to-the-land movement, the Dunlite was one of the major machines installed in the U.S. Notice the governor's weights. There are number of machines in Canada: several in B.C., one at AWTS, and the Nova Scotia Power Company operates one. Jerry Ball has three up at his shop in Wellington, Ontario. Many have been imported from Australia to the U.S. With a maximum power of 3 kW, they cost about $4,700 ($Can). Careful Ecosystems in B.C. found the manufacturer's lubricant too heavy for Canadian winters, instead they us very light 20/20, 10/10 (?) oil. AWTS found that autolite transmission fluid works quite well in their unit.

Here is a very reliable 4 kW Aerowatt installed at Parc des Anciens Combatants, Ville Laval, Quebec. These require minimum maintenance and apparently last for 50 years (!). These are conservatively rated at a 15 mph windspeed but are roughly twice as expensive as units designed to last for 20 years - so may still be ahead in life-cycle cost. Hydro Quebec paid several thousand dollars for three of the firm's smallest product size - 150 watts - for use in a hydroelectric project along the Great Whale River in northern Quebec. I don't know if the 4 kW unit that powers lighting for the war memorial produces more than 4 kW above its 15 mph rated windspeed.

This slide shows a seven bladed 200 W Lubing from West Germany. One of the fibreglass blades has been slightly damaged. These come in both water pumping and electric generator versions. Notice high solidity and extremely flat blades. I think the company sells more of the water pumpers than the electric generators.

At Tvind, Denmark we find the world's ultimate homebuilt. It's designed to put out 2 MW but is presently limited to a 1 MW peak because the grid can't handle more. Many components were donated by the community college (which it powers and heats). They built the blades themselves in large jigs using boat-building technology. This community of skilled people worked to establish greater energy self-reliance through this project which at this time has yet to be duplicated or surpassed anywhere else in the world. The Hamilton Standard Co. in the U.S. is building blades a little bit bigger in size using similar techniques for the Swedish government and the U.S. Department of the Interior.

Swedish government and the U.S. Department of the Interior. There is also a 40 kW medium size rotor at the site. It typifies a new generation of machinery replacing old standbys such as Electro with such new names as: Danskvindcraft and the Danish Association of Blacksmiths. Blades are made of fibreglass with gearing similar in design to that in larger machines. They build these machines before the larger ones in order to gain experience.

Here is a close-up shot of a Danish machine erected in 1980 at Homer Spit, Alaska. Note the pinwheel rotors which guide this upwind machine into the wind. As the wind shifts it catches the pinwheels which turn a pinion gear that slowly yaws the turbine. Hence no need for a tail. The machine was designed and installed under the supervision of a representative from the Danish Renewable Energy Organization. He was imported from Denmark by Steve Smiley on a U.S. appropriate technology grant. It is currently interfaced with the local utility.

Here is a homebuilt machine with rather pinwheel-like blades located somewhere in southern Ontario. There is a commercial machine like that called the Chalk turbine. It has a tail. high-solidity, wide chord rotor. It was designed to rotate at a slow rpm so it won't 'fly apart' as readily as a high speed homebuilt machine might. If you do a homebuilt with this type of rotor, it might last a few years and be worth the few hundred dollars you put into it.

Here is a shot of another huge, mysterious, pretty advanced homebuilt. I don't know where it is. It looks like a helicopter hub and the blades seem to have a kink in them where the trailing edge at this point 'does this' while the leading edge stays straight. It has a big wave in them like helicopter blades. I saw a machine like this in Calgary though it never worked.

Perhaps the most well-funded homebuilders are Rangi and South of NRC when they reinvented the Darrieus. Note how the blades were bent in a special 'on-site' jig rather than curved in the intial proof-of-concept prototype. Since you can bend accurately it worked reasonably well without balancing problems. The bearings are on shaft extensions way above the top and below the bottom of where the curved blades met. They decided not to use the cantilevered tower used in other Darrieus projects.

Here is a shot of the Darrieus on the roof of the Renewable Energy Exhibit adjacent to the Rideau Falls in Ottawa. This machine, which is similar to the one on the roof of the Monetary Times building at Ryerson Polytechnical Institute, rarely spins. The tower is kind of nice, don't have to guy it so can set it up anywhere.

This Darrieus, built by Bristol Aerospace, uses the cantilevered tower so it could be mounted on an ice flow and set adrift in the Arctic to collect meteorological data. Note the two S-rotors at the top and bottom to make the unit self-starting. Outside here you'd have these legs which sat on pads so you didn't have to guy it. This machine was set adrift in the Beaufort Sea in the 70's and provided good service until it drifted into Soviet waters. The blades were made of stainless steel. While there is nothing on a homestead scale yet, Bristol is making small units below 40 kW for remote site purposes such as telecommunications electrical supply and weather station monitoring.

Barber Hydraulics built three 40 - 50 kW Darrieus rotors with bent blades rather than curved airfoils with air brake flaps. These were built for the Northern Canada Power Commission and at least one unit was erected at Frobisher Bay. It was accidentally disconnected from its load, began to freewheel then flew apart. After that the NCPC disregarded wind systems because they felt the winds were too strong. While I do not know their cost, NCPC has one unit in storage and the other unit is lying around somewhere.

Here is the first NRC Darrieus with curved blades, three of them, in their large horizontal wind tunnel. They eventually put this one on the roof of NRC. This model was probably fabricated by DAF Indal.

The University of Manitoba built and operated a Darrieus with blades made of wood. This approach is questionable as the wood flexes much more than metal and there may be balance problems when spinning. However, there may be less danger around a wood machine vs. a metal machine if it flew apart. They are still working on this type of design.

This is a photograph of the Hydrowind which was designed by an aerodynamic engineer in the U.S.A. for the New Alchemy Institute's ark project in P.E.I. I don't know if it ever delivered power, there was a big contract wrangle between the New Alchemy Institute and the federal government because of it. It was designed with a hydraulic transmission so that eventually four windmills could be hooked together with each rotor pumping hydraulic fluid through pipes driving one small turbine coupled to an electric generator. It may not have worked but it sure looked nice.

This shot shows a collection of machines at the Brace Research Institute in Montreal. This group showed us how to cut 45 gallon oil drums into Savonius rotors for 3rd world water pumping. Also sail-wing windmills. The tower is a Buckminster Fuller tetrahedron module design. The original Brace Savonius is on the roof of McGill University in Montreal.

They are working on a project with twin Savonius rotors at the University of Laval in Quebec. While this is not shown here, instead of two blades they used six blades mounted very close together which meshed together as they spun like a hand-held egg beater. There was a shroud around the outside to concentrate the wind flow into the area between the blades. In the summer of 1980 we wrote a story on one of the two prototype machines which the designers called Adam and Eve. Incidentally, please keep an eye out for the Wind Power Report supplement which I am editing for the February 1982 issue of Renewable Energy News.

A view of some of the activity at Goddard College in Vermont. The Savonius on the roof of the house, a waterpumper, and a sail wing device being assembled in the background.

Nigel Florida and another person built a straight blade Darrieus with two airfoils for the Grindstone Island Cooperative near Kingston. There are a number of small Savonius rotors in the middle for start-up. The machine is shown here lying on its side. It has not been tested yet.

D. Platnick: The fantail (pinwheel) mechanism for turning wind machines into the wind was originally patented in Britain circa 1732 - 83. Another company which builds a downwind machine with fantails to keep it into the wind is the Whirlwind Power Co.

THE HELICAL WIND ENGINE
The Story Unfolds

Nicholas Teekman
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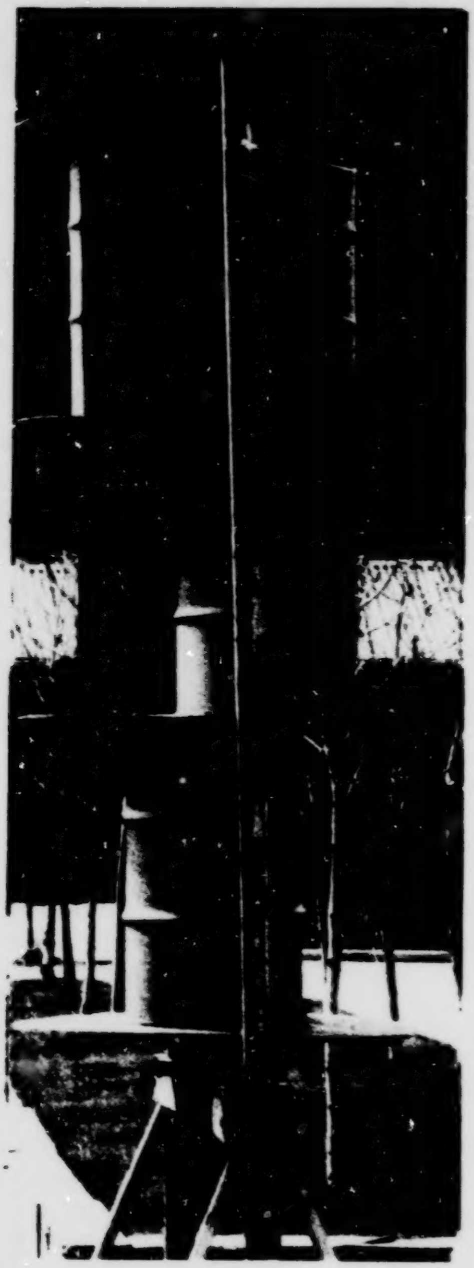
INTRODUCTION

I have been in wind energy research since 1976, travelling around the countryside from the Maritimes to Central Canada looking at windmills, attending meetings of interest to people who want to do or learn something, or just dropped in on people in the countryside. We'd be driving along and see-something-over-there, somebody has been tinkering! We would stop, go up and say 'hello' and start a conversation.

It seems to happen that when you get into this whole wind and renewable energy business, it becomes almost as much a story about the people as the actual work they have done. I'm going to recount our story, our experiences in exploring this business, and explain what has been achieved over three years.

BACKGROUND OVERVIEW

Savonius:



This is a Savonius which was built in the fall of 1978. It was initially installed on a property near Hillsburgh, Ontario.

In the first attempt to raise the windmill, a pulley was attached to a TV tower on the side of the house. Blue five strand clothesline wire ran from the top of the Savonius through the pulley to a van bumper. As the van moved forward, the rotor tilted up part way. However, the clothesline slipped out of the pulley, got pinched on the pulley axle, and snapped. The rotor went straight back down again - BANG! However, most of the weight is in the massive rotor which hit the ground directly. Consequently, there was no damage to the bearings or support structure. One of the nice features about dropping a Savonius of that weight.

It was on exhibit at the 1978 Canadian Energy Exposition at Harbourfront where it was set up and allowed to free wheel in the parking lot. While an associate was tending it we had the good fortune of promoting it to Allistair Gillespie, who was the Minister of Energy, Mines and Resources Canada at that time. This thing has certainly had its uses although we haven't got one kW-h of electricity out of it.

Notice the water pump from a washing machine. The base bearing is the front hub from an Austin 1100 because the bearing is designed to take axial as well as radial loads. Usually its axis is horizontal, but even though we use it flat on its backplate its tapered roller bearings will take the loading when its axis is vertical. The upper bearing is a self-aligning ball bearing for a 1" diameter shaft. An associate found it in a Massey-Fergusson snow blower. You can just order the part at a Massey-Fergusson dealer. A plywood disc was mounted on the hub underneath the rotor and was shimmed to rotate without wobbling. When the wind blew we were not too ambitious, we just held up a round chisel and notched a groove.

Note the tool box which housed a Bosch generator complete with its regulator. However, the Bosch generator is made to run horizontally whereas we were operating it vertically, so eventually the bearings siezed.

When this thing spins, it can really go at a clip. In high winds, when the rotor is galloping, it likes 'stamping' and 'walking' across the ground. Apparently in the spring storm that flooded downtown Port Hope in 1980, it not only walked off its concrete block base pads but the generator siezed. There are burn marks on the plywood disk from the sudden braking. Afterwards, the rotor was tilted back onto its side. This was a mistake because it put a big 'wow' in the rotor assembly, which took at least 3 - 4 months of the rotor standing upright to settle out to permit proper running again.

The tool box was since taken over by a bird and nest. However, the rotor was accidentally unleashed in an afternoon summer squall. It took off before it could be braked and began to stamp the ground. The squall blew through in about one hour. The chicks were OK but after a few days, mother and chicks had left that nest.

We've just coloured it up a bit so now it is useful. It is a scarecrow to keep the birds out of the garden.

That device is now 4 years old which isn't bad for steel drums, recycled nuts and bolts, and pieces of wood obtained from a farmer's swamp and finished at a saw mill.

Hydrowind:

The Hydrowind has had a checkered past, it is is one of your noble failures. It is twenty feet in diameter with hydraulic pitch control. The aeronautical engineer that built this did incredible handiwork on the blades. It is all pop riveted to aircraft type standards.

Hydrowind was originally designed under the auspices of the New Alchemy Institute in Cape Cod, Massachusetts for the Ark Project in P.E.I. When it was being installed the boom on the crane jammed so it was left hanging overnight. While in this position, the wind blew the machine against the tower bending the shaft. Eventually it was repaired and reinstalled.
The idea was to pump up hydraulic fluid with the wind turbine, with some of the energy stored in reservoirs. You could plug as many turbines and alternators together as you wished into the hydraulic stream to custom design the system to provide as much power as you needed. Great idea - but it didn't work, too many losses. I think this is one of the generators down here for taking the power off. When you mentioned, "let's make a 5 Hp compressor and just run it", that too will be very lossy. I think for a Bowjohn type application it is great, but for something bigger you're better off putting a generator up top to power a compressor at the base rather than a direct drive compressor on the wind shaft.

Today the Hydrowind is just sitting in a shed at the Ark on P.E.I. doing nothing.

Darrieus:

There's the Darrieus which we just viewed on the roof here at Ryerson at lunch. In it's infant state because no electric motor has been hooked to it yet.

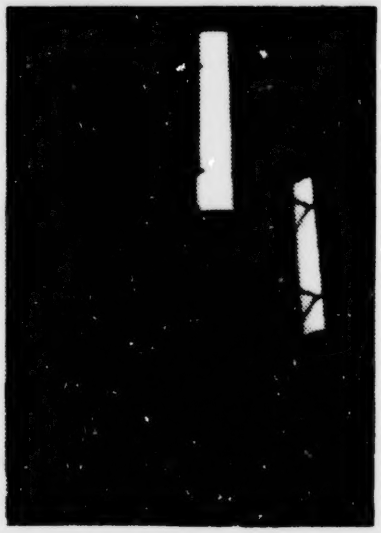
Q - Is the generator still up there?

A - Yes, we ought to get this unit out to the Kortright Centre.
(Now at Kortright Centre - ed.)

This Darrieus was behind the Ark in P.E.I. DAF Indal again, it's at the Atlantic Wind Test Site now, way at the opposite end of P.E.I. This originally was a hydraulic unit which had a churn underneath to heat up hydraulic fluid. The fluid was then passed through a heat exchanger in the Ark to contribute to that structure's heating needs. However, it didn't work effectively in this configuration. It's now set up again to be operated in an electric generation mode at AWTS.

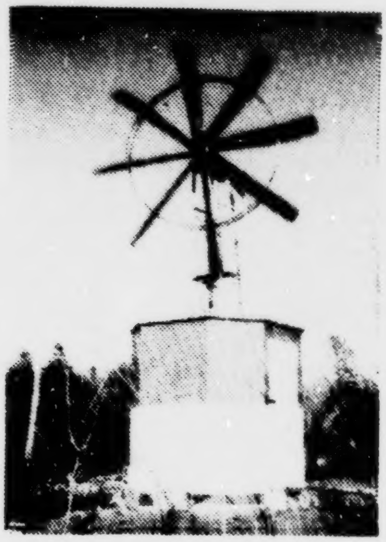
The Darrieus, although simple, is not a very efficient machine. In addition, it is not self-starting and has a tendency to stall in gusty wind regimes.

Straight Blade Vertical Axis Wind Turbine (VAWT)



This is a straight bladed VAWT that originally evolved out of the Airfish design. It was exhibited at the SESCI meeting on P.E.I. back in 1979, spinning away in the hope of attracting the interest of the Institute of Man and Resources. It was being tested recently at the Toronto Island Airport. It has been dismantled however to prepare for that airport's expansion. The blade is 14 feet high with a 23" chord and flies in a 17 foot diameter circle. (I don't know if it was ever loaded down.) Some tests were made in early fall 1982, but the results were all preliminary. I remember going across on the ferry to Hanlan's Point next to the airport. I borrowed somebody's binoculars to see if I could see this thing. I was impressed. It stood taller than all of the tails from the airplanes on the runway. Some of those planes were good sized. It was a big machine, more so than this slide indicates. You can see the ladder there when it was erected at Dundas, Ontario.

High Solidity HAWT



A homebuilt photographed in New Brunswick. The gentleman worked for the New Brunswick Electric Power Commission. The important thing about the design is the high solidity. You can see the tail vane in behind. He found that when the tail vane fell off, it would still hunt the wind by itself. Its an upwind machine. That was something I couldn't figure out. Another thing was a huge alternator that was ..... down at the bottom. He used two rear axles for the speed increasers. Even so, he could twist 3/4" strapping like pretzels with that thing.

HELICAL WIND ENGINE

****

RENEWABLE DYNAMICS' CORPORATE GOAL

Our company is attempting to get into a position in the wind energy business around a generic design or product that would, in our opinion, have a good chance of being marketed.

Because of the diversity intrinsic to the nature of the resource, it must be marketable to as wide a range of opportunities as possible.

A unit that can go just about anywhere could be more readily marketed.

It must be 'comparatively' inexpensive compared to other alternatives to contribute to its marketing potential.

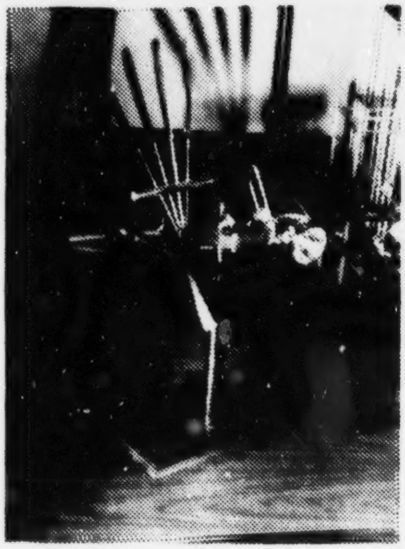
It must be a fairly efficient unit over a broad spectrum of wind speeds. If one knows the wind, one should know that there would be no other machine that would give more energy than this particular unit for a given diameter for an equivalent price.

RESEARCH, TEST AND DEVELOPMENT PROGRAM

In March 1980, an article came out in 'Popular Science' on the Helical Wind Engine and its inventor in Detroit, Michigan. The story was impressive enough that we visited him in Detroit to see what it was all about.

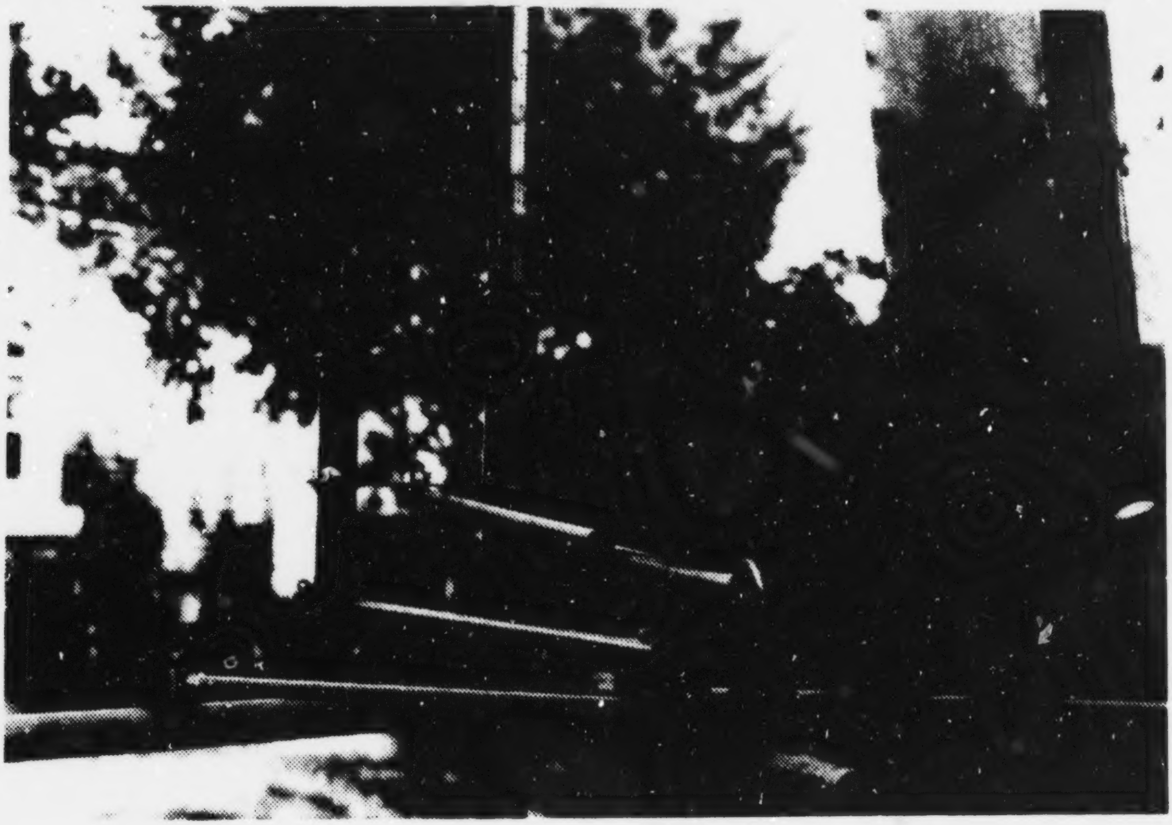
The inventor is an automotive engineer who retired from the Ford Motor Co. in 1973. He has a substantial background in production engineering in the Detroit automotive industry.

He showed us his presentation down pat. He started with a 16 mm film of the Mod 01 and a few other windmills. Then he showed a film of the vertical lift translator windmill that he made. I don't know if you know what that looks like in theory, but it is a series of stabilized kites on a huge conveyor belt. The kites just soar up and down. It worked, it looked like something out of: "Those Incredible Men in Their Flying Machines" the way it just flew around and bounced. It was really quite something to see. He designed it so that the kite would stay at its optimum angle of attack as it flew up and down, it wouldn't flap. He is a pretty determined craftsman.



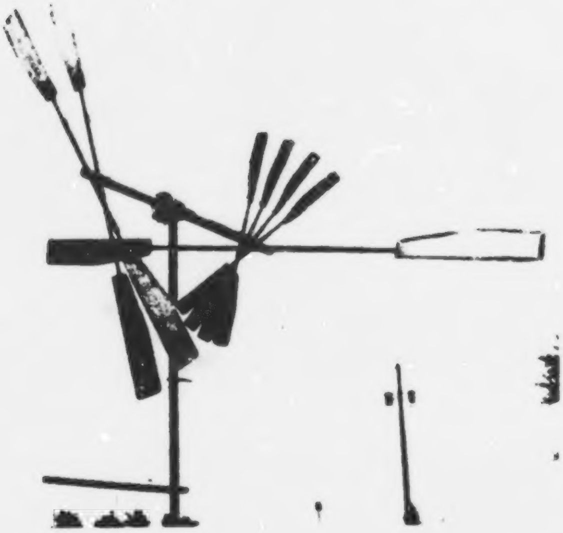
This figure is a model that was presented at the 1980 Wind Energy Symposium at the Highland Energy Centre, Orangeville. It is made out of brass and shows the helical arrangement. Notice in all the inventor's models, the meticulous craftsmanship and workmanship put into them. They were all made in his basement workshop out of brass mostly or wood or glued layers of formica floor tiles. In this figure an 18" diameter 8-bladed, brass model powers a bicycle generator and headlight.

Here is a standard Wincharger mounted on the inventor's suburban home. Notice the gizmo on top, the two vanes? The wind pushes the vanes together which pulls a string. As the string is pulled, it turns on more and more resistance heaters to maintain a loading proportional to the power in the wind. It's kind of neat, perhaps not practical but it works.

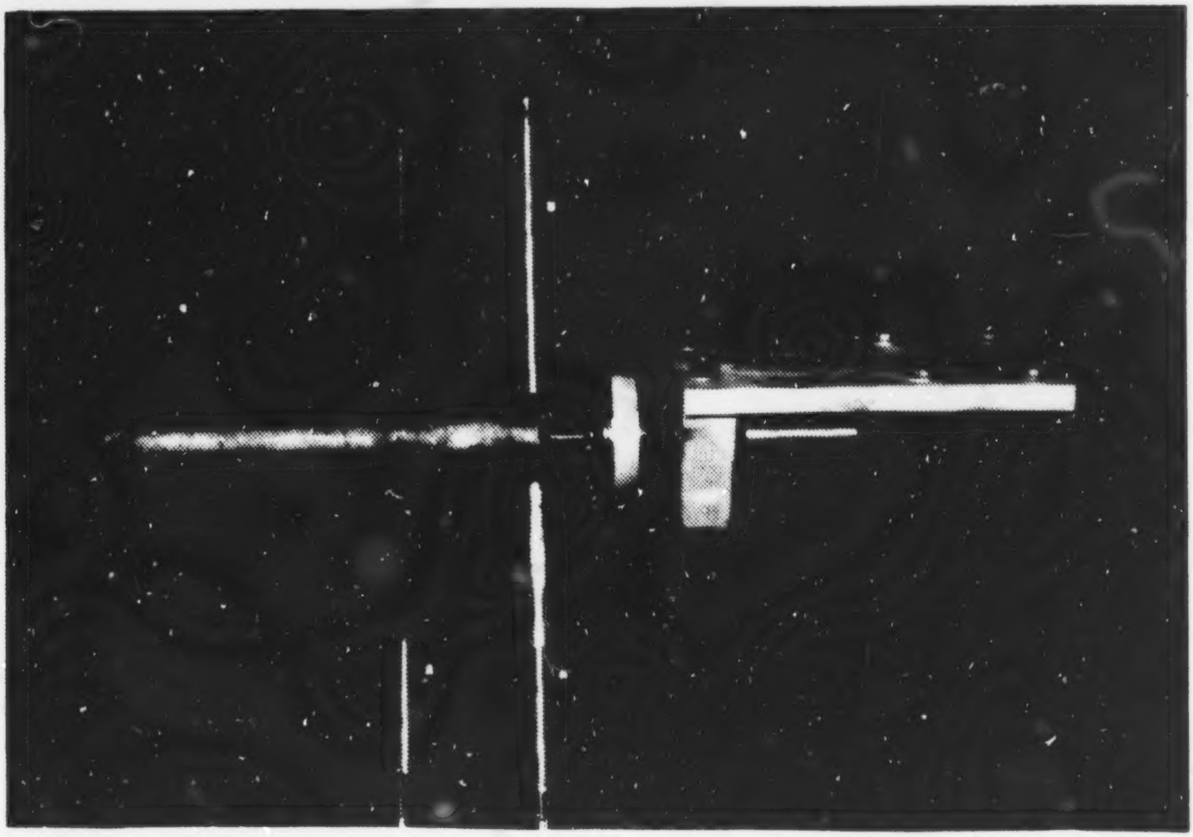


Just some construction details on his tail vanes. This is the steering mechanism: the slider, the rotor post, the return spring, the arm that goes to the pin on the rotor support post. As the spring goes back it pulls back the pin on the rotor support post and thus turns the head at right angles to the wind.

There's the cam there. And that's in the relaxed position.



More slides illustrating the quality of the workmanship of the inventor. That is just a regular truck front wheel bearing from a Fiat that this WS-482-8 model is rotating on. It is 8 feet in diameter with brass blades and vane-compression steering mechanism. You are dealing with somebody who knows their



materials and how to shape them. Even if the low speed aerodynamics should turn out to be invalid, one still learns something about how to make machines. We saw some 200 models on different designs that he had tried.

The inventor would drive on highways down to New Mexico with a WS-482-8 mounted on a trailer behind his car to demonstrate to people. He is in his middle, late seventies but he is set to move. One of the big things that we learned from him was as the .....(STATIC).... became less valid, the efficiencies, a lot of things we weren't happy with.

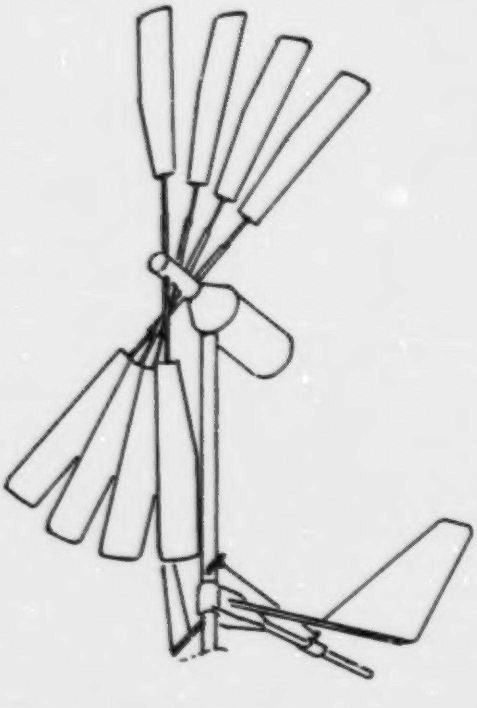
DESIGN FEATURES

The design guideline in assessing the outcome of tests on variations in the design elements was to achieve: "maximum horsepower at minimum cost".

What is unique about the approach is that it is based on 'drag' rather than 'lift' aerodynamic principles.

According to the inventor, the interesting properties of the helical design are:

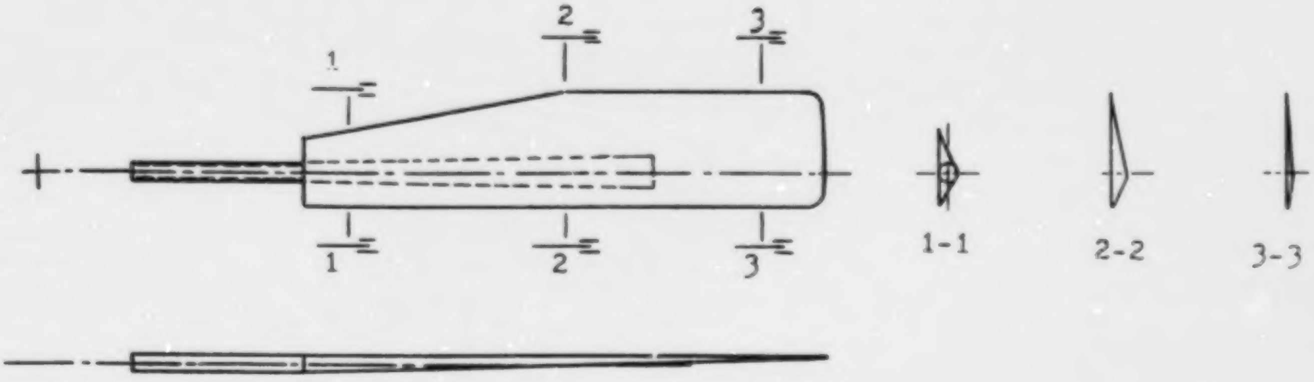
- HIGH EFFICIENCY WITH HIGH SHAFT TORQUE AT LOW RPM



HELICAL MULTIVANE
Sizes to 30 feet in diameter
U.S. Patent "4,065,225"

The key to this is blade design and blade-pair helical twist. The design principle of the helical wind engine is that the blades move through the air with greatest power extraction efficiency in lower windspeeds. Not necessarily highest rpm, but the maximization of the torque/rpm physical relationship to produce maximum horsepower.

- PATENTED TRIANGULAR SHAPED AIRFOIL BLADE DESIGN



HIGH PERFORMANCE BLADE
U.S. PATENT "4,171,929"

It is thick and symmetric at the heel of the blade then it gradually flattens as one moves out to the tip. It gets very flat.

It has a fixed pitch angle of attack determined solely by the number of blade-pairs working the swept area.

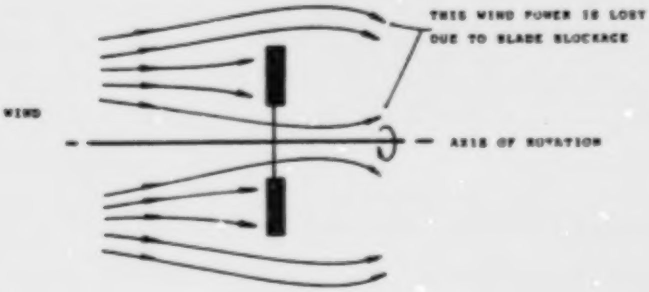
The blade sweeps only the outer one-quarter to one-third of the diameter of the swept area, because that is where all the torque is located.

Presently, low speed aerodynamic theory sees lift becoming substantially greater than drag at Reynold's Numbers greater than 100,000. Below this value the shape of the airfoil doesn't matter that much. Consequently, this triangular profile airfoil has been deliberately designed to act as an air brake to help limit rotor rpm in higher wind speeds.

- PATENTED HELICAL TWIST

What happens with any windmill is that above a certain windspeed the blades are spinning fast enough that they essentially become a solid disk to the oncoming wind. At this point, instead of the wind going through the blades it just gets pushed around the outside of the rotor diameter, thus the rotor loses energy.

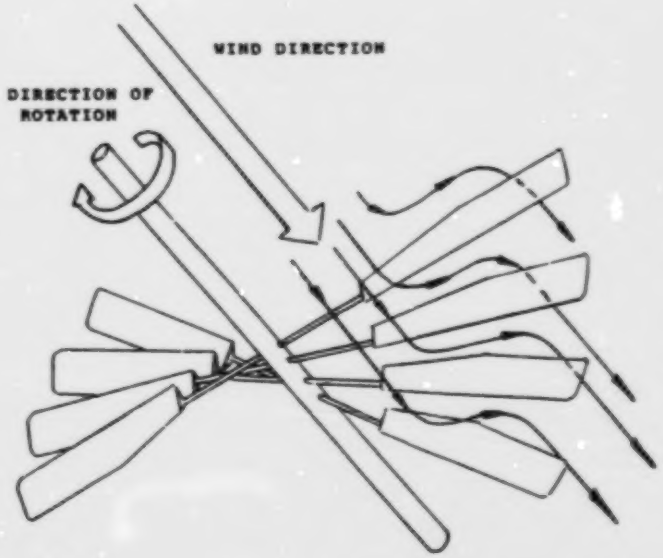
THE FLOW OF AIR AROUND WINDMILLS


THIS WIND POWER IS LOST
DUE TO BLADE BLOCKAGE
WIND
AXIS OF ROTATION

CONVENTIONAL WINDMILL

Through experimentation, the blades have been placed in a helical configuration so that up to the wind speed for which the rotor has been tuned for peak efficiency, the blades will slice around and sweep energy out, allowing the turbulent air column to pass through the swept area before the other half of the blade-pairs come sailing around.

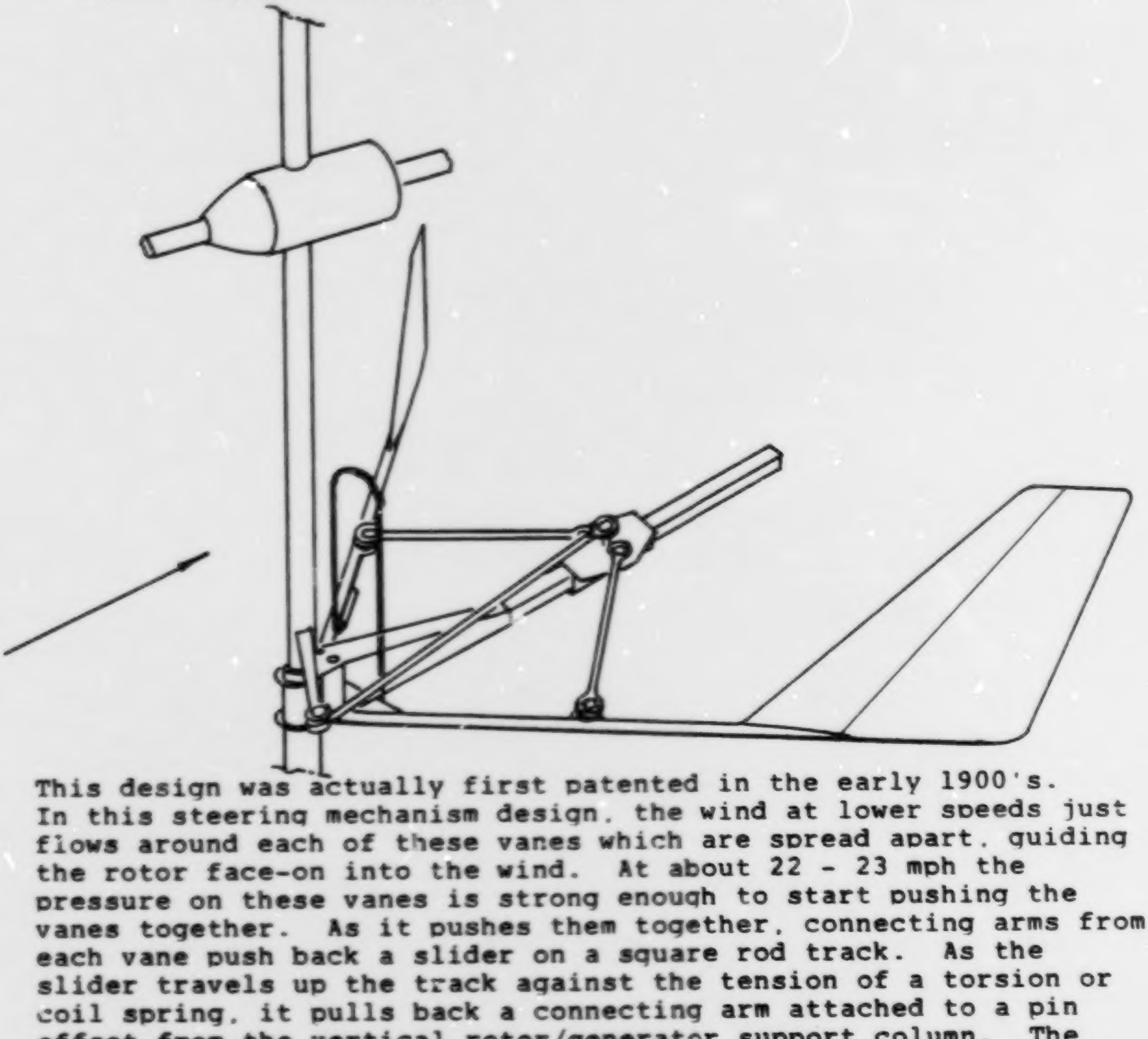
THE FLOW OF AIR THROUGH THE
HELICAL MULTI-BLADE WINDMILL


WIND DIRECTION
DIRECTION OF ROTATION

- ITS REPLICATION

Blades for any diameter machine retain exactly the same proportion. The basic design is numerically simple to scale up to an 80 foot diameter. This makes the design suitable for mass production, particularly with CAD/CAM. Blades can be fabricated by jig welding of stamped tubing with sheet metal. Prior to welding, the metal sheet has undergone only three press brake operations after the pattern is cut. Alternatively the blades could be made from fiberglass-reinforced injection molded plastic.

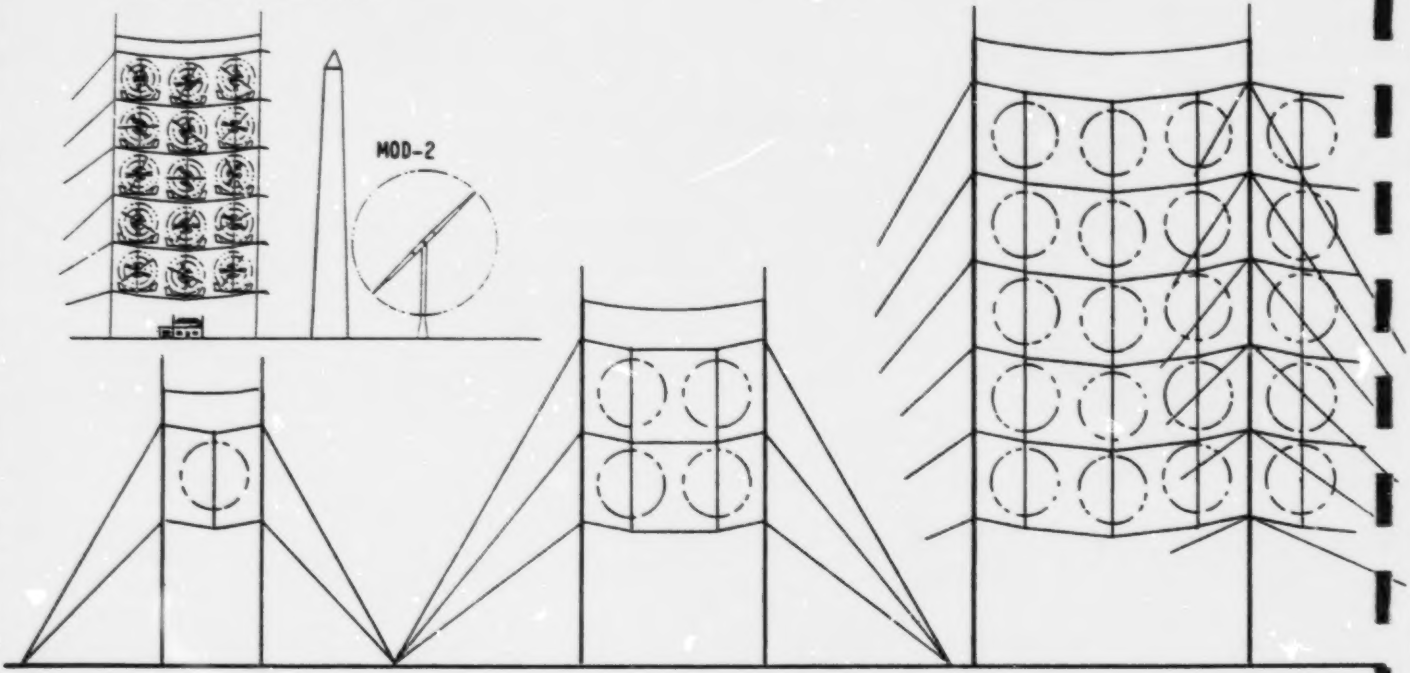
- UNIQUE STEERING MECHANISM



This design was actually first patented in the early 1900's. In this steering mechanism design, the wind at lower speeds just flows around each of these vanes which are spread apart, guiding the rotor face-on into the wind. At about 22 - 23 mph the pressure on these vanes is strong enough to start pushing the vanes together. As it pushes them together, connecting arms from each vane push back a slider on a square rod track. As the slider travels up the track against the tension of a torsion or coil spring, it pulls back a connecting arm attached to a pin offset from the vertical rotor/generator support column. The rotor is thus turned by about 90 degrees which reduces the wind loading on the tower. It is a fixed pitch machine whose power production is regulated automatically by the tail mechanism turning the rotor into or out of the wind.

- 'CLOTHESLINE' VERTICAL STACKING IN ARRAYS FOR WINDFARM APPLICATIONS

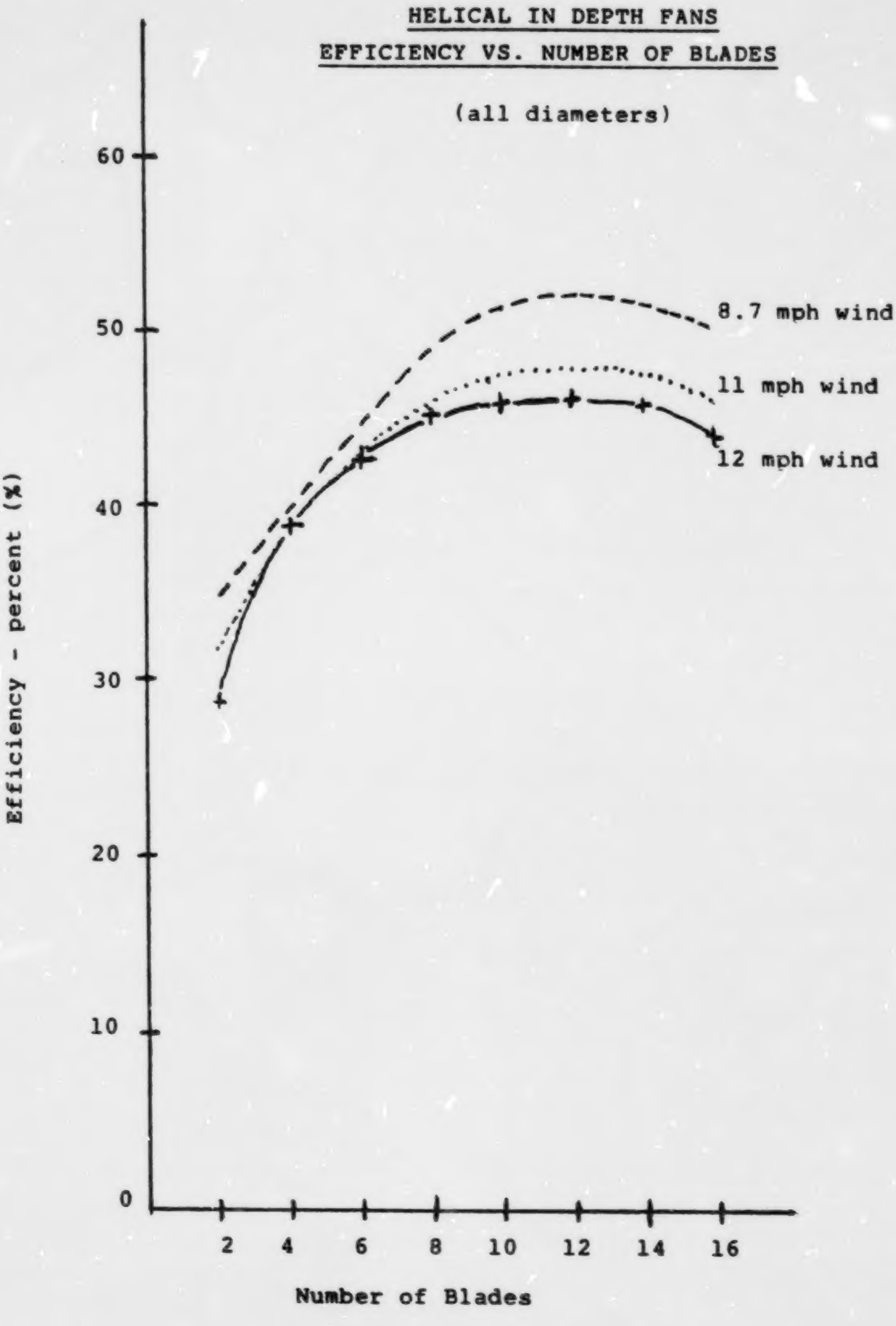
The idea is eventually to build a modular concept, where these things are mounted in arrays once the basic design is solidly established. These could then be stacked according to, I think, how much the public is willing to tolerate them rather than intrinsic limits on the total amount of energy available in the wind. Patents have been taken out on the modular concept and hook-up mechanisms. The inventor has even been trying to negotiate into the whole California windfarm scene in the Mountain passes.



HIGH TOWER AND CABLE MOUNTING
Wind power plants of any desired size.

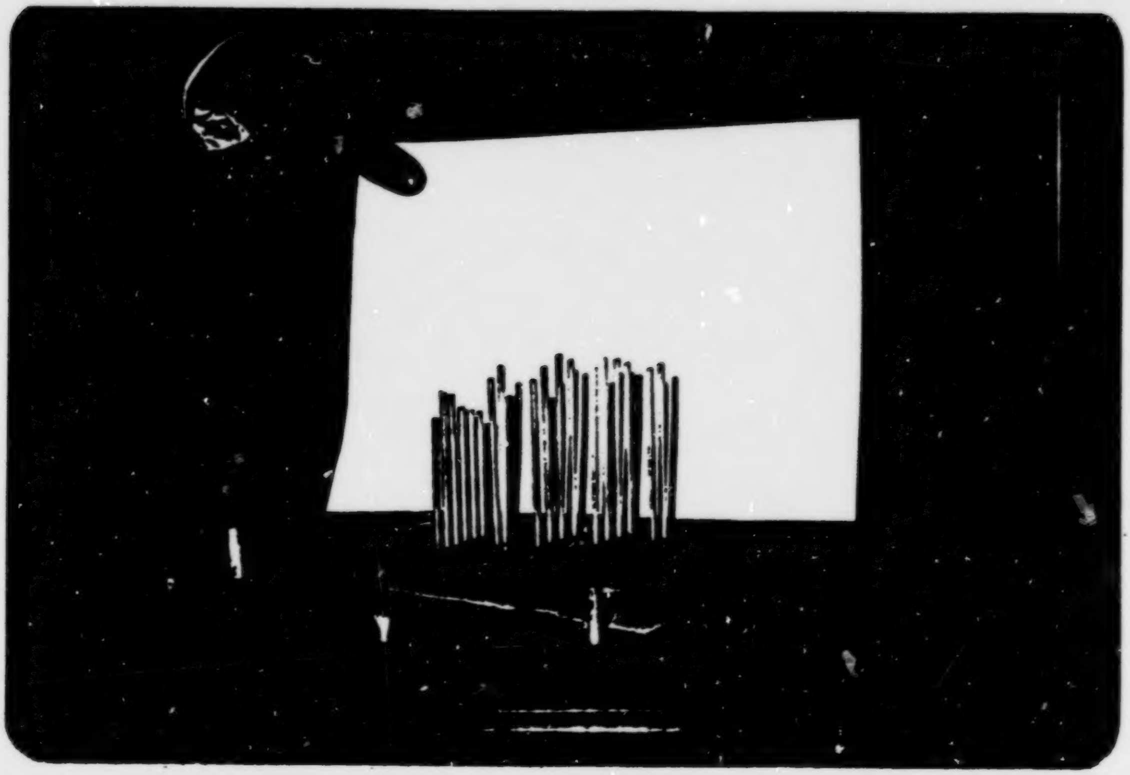
WIND ENGINE EFFICIENCY

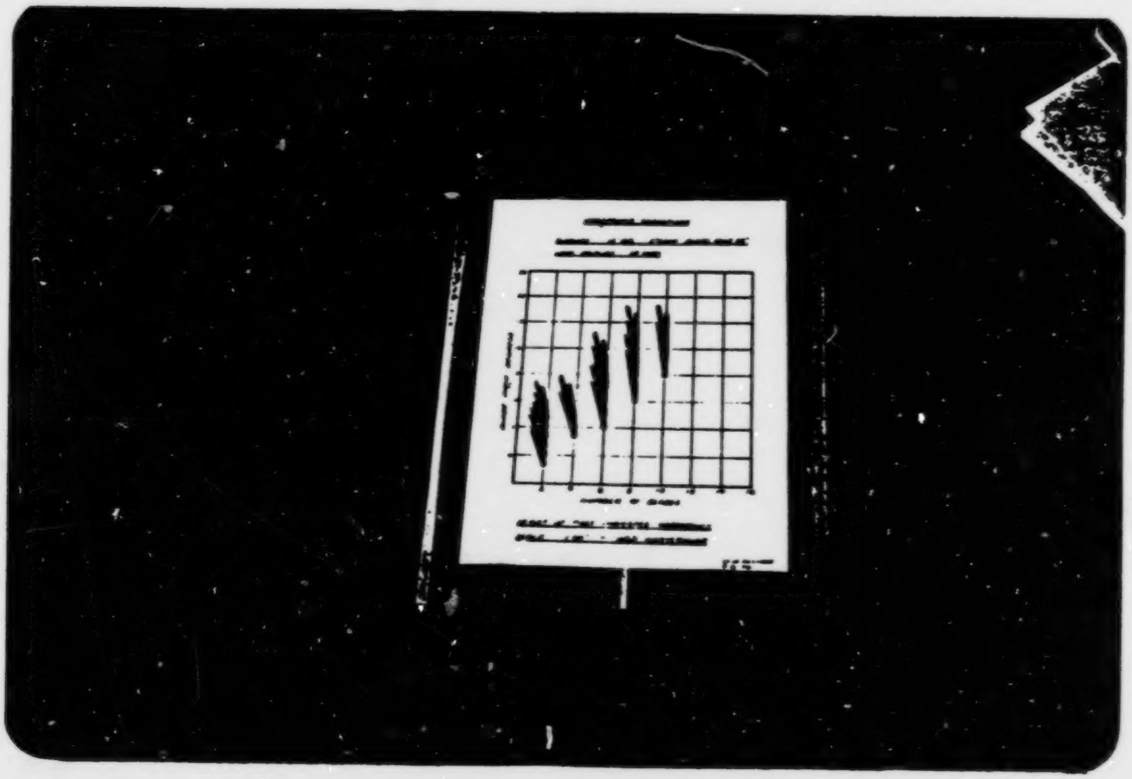
The helical design can be tuned in efficiency for a given wind speed. If you put more blade-pairs on, it reaches its peak efficiency in a lower windspeed. It can go up to 5 or 6 blade pairs. This figure shows efficiency vs. number of blades from 8 blade-pairs (sixteen blades) down to one blade-pair (two blades). The 'maximum power' angle of attack of the airfoil has been empirically correlated to the number of blade-pairs of a given rotor configuration.



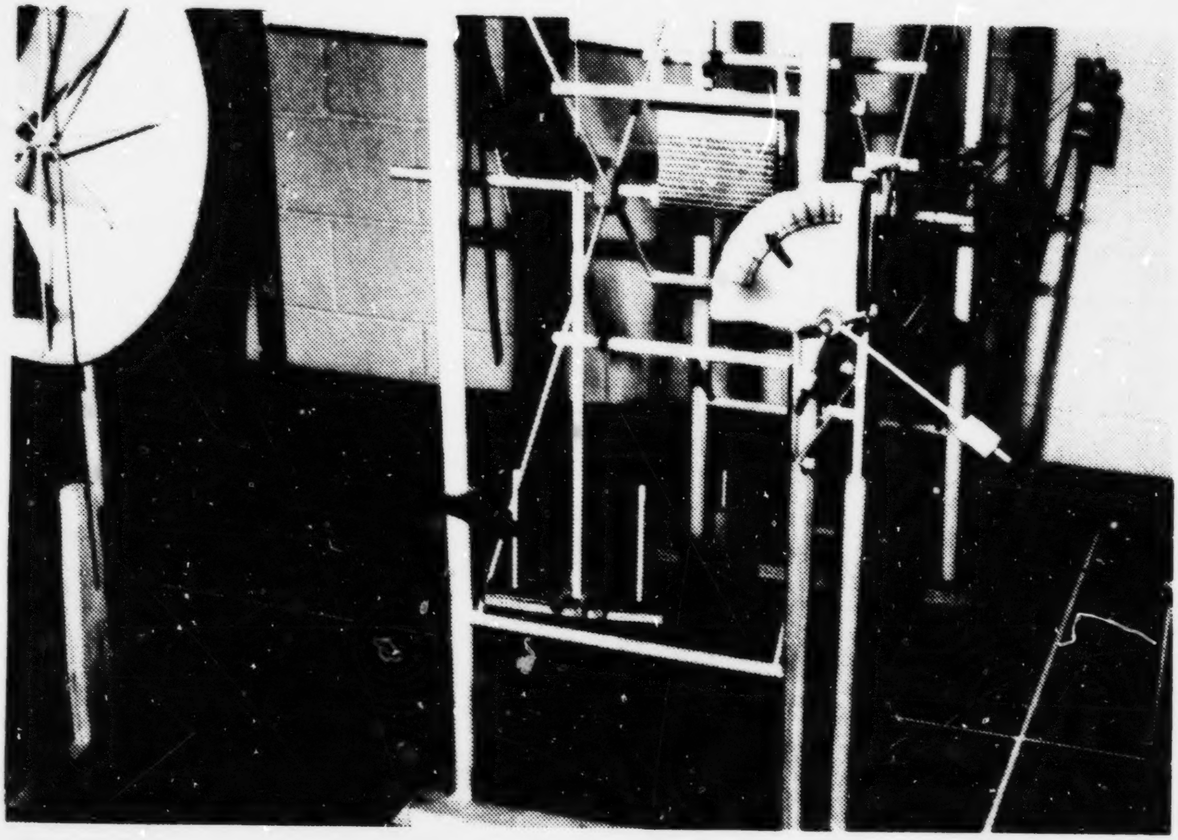
HELICAL IN DEPTH FANS
EFFICIENCY VS. NUMBER OF BLADES

(all diameters)

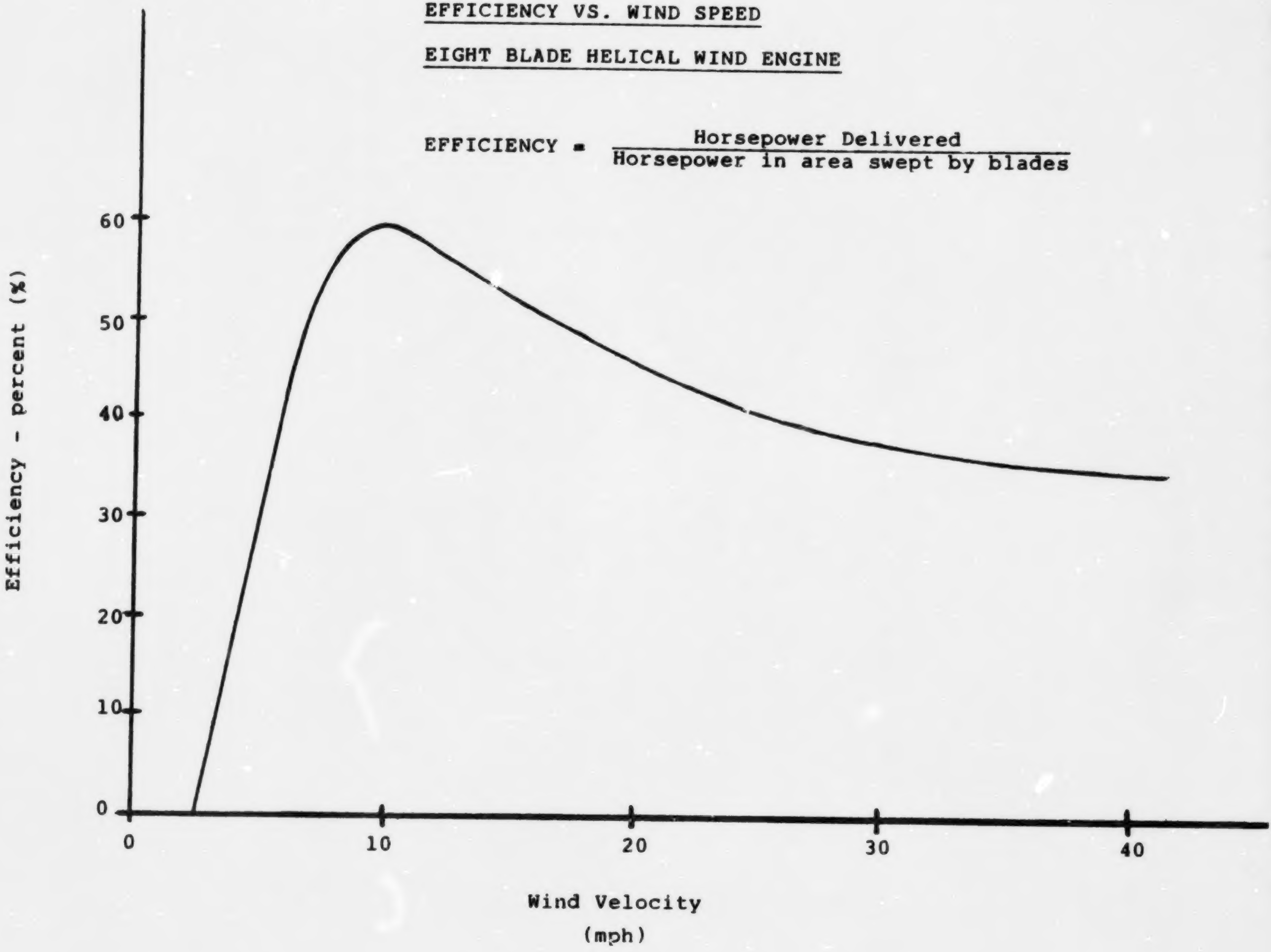




Usually efficiency is equated with the shape of the airfoil and the speed that they are rotating. The inventor claims that the peak efficiency of the machine relative to windspeed is a function just of the number of blade-pairs. According to his calculations and measurements, peak efficiency for a 12 mph wind is obtained with 5 to 6 blade-pairs. At an 8.7 mph wind, you are farther out here at about six blade-pairs (twelve blades). If you're average wind was 11 mph, you'd get your most efficient extraction of energy from the wind with a 5 blade-pair machine.



This figure shows the most interesting part about the design, the projected peak efficiency of a 4 blade-pair unit. It is based on measurements made by the inventor on his scratch-built dynamometer. It projects that the peak efficiency is somewhere between 50 and 60 percent in terms of available shaft horsepower. It is this claim which we are trying to verify against the inventor's measurements.



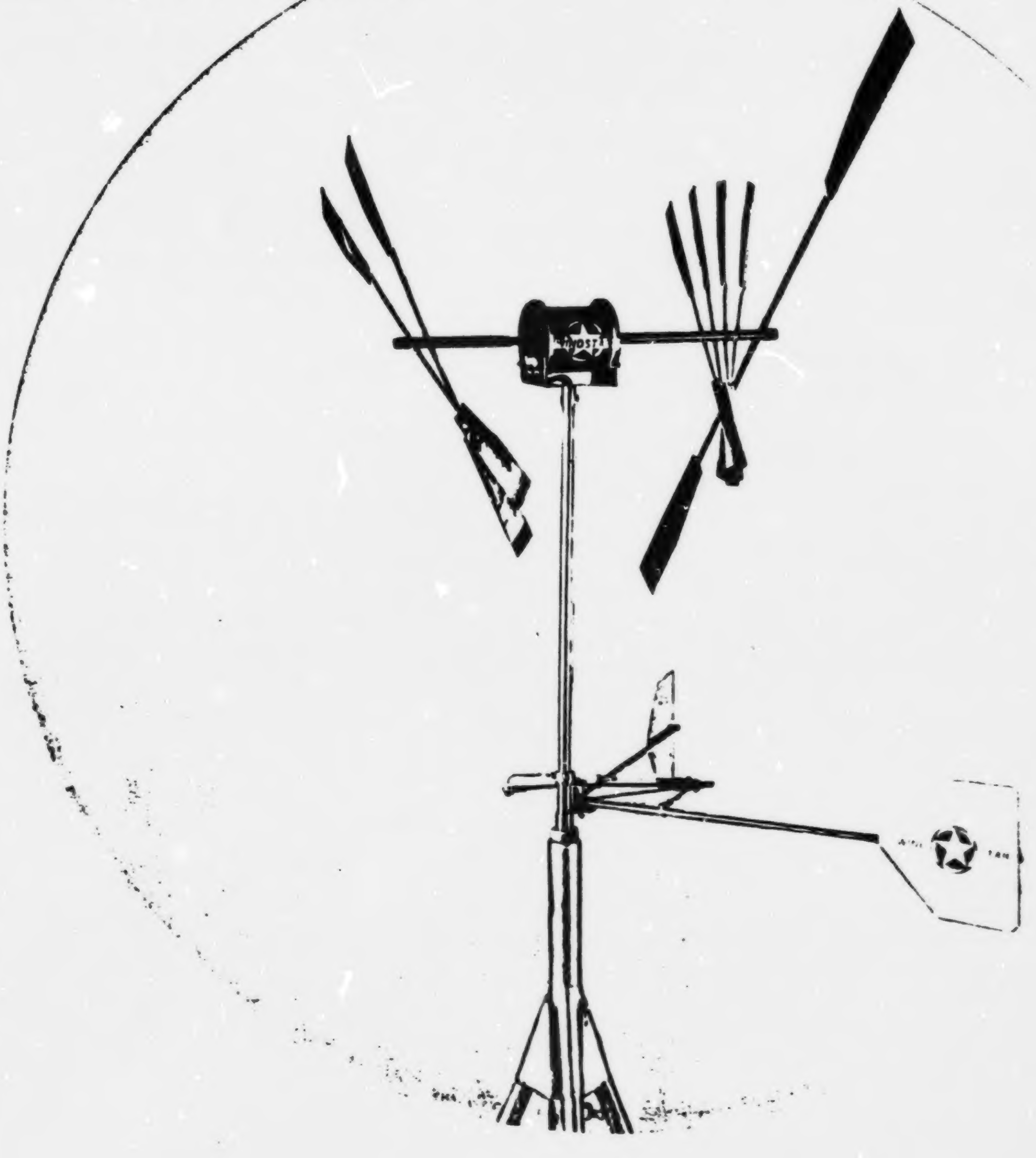
EFFICIENCY VS. WIND SPEED

EIGHT BLADE HELICAL WIND ENGINE

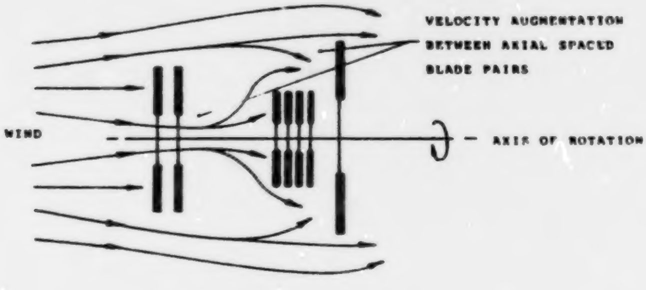
$$\text{EFFICIENCY} = \frac{\text{Horsepower Delivered}}{\text{Horsepower in area swept by blades}}$$

I think Lawrence Schienbein showed a graph of the efficiency of the Darrieus. According to the inventor, this is the way the efficiency works over windspeed for a four blade-pair standard helical configuration. Efficiency is defined as "(Horsepower Delivered)/(Horsepower in Area Swept by Blades)". In the inventor's efficiency calculations, 'swept area' is strictly interpreted as NOT including the central area about the hub which is swept by the spar lengths supporting the airfoil. In the case of an 8-blader, it will reach its peak efficiency at approximately 10 mph and then fall off. This fall-off is not necessarily a bad feature, because the power in the wind increases as the cube of the windspeed. To save your machine, you must dump excess energy at higher windspeeds. But you want to have peak efficiency at lower wind speeds to maximize output where there is not as much energy in the wind according to the cube law.

COMPOUND HELICAL WIND ENGINE

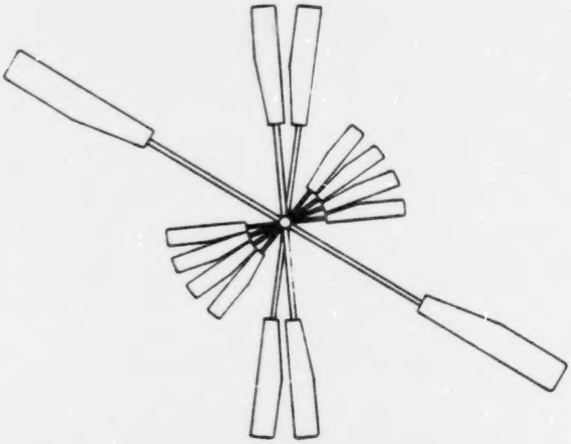


This is a compound helical wind engine. This is the one that is being tested at the Atlantic Wind Test Site in Prince Edward Island and at Shelter Valley Centre, Ontario, 75 miles east of Toronto.



WINDSTAR WINDMILL

The idea behind the compound helical is to use a multistage turbine approach to capture more energy from the windstream. What wind is spilled by the leading medium diameter blades is either accelerated through a venturi effect in the centre to be captured by the small inner diameter blade-pairs or flows outward to be captured by the larger outer diameter blade-pair.



This is the compound helical viewed head-on. Notice the way there is the balance of 3-blade machines incorporated in its design for yaw stability in following the wind. The 2-bladed machines tend to clatter as they yaw. In this design there is 60 degrees separating the mid-points of all of those blade sets. So it retains a multiple of that 120 degrees angle that the 3-bladed machine would have to balance the forces as the machine yaws to track the wind.

Q Looking at that picture, could you just mark the diameters of the aft blade sets?

A These are the foremost blades here, then you come to the pivot point then you come to the innermost diameter blades and finally the outermost diameter blades.

This configuration is described is as a WS-482, and then there is a dash followed by the diameter (e.g. WS-482-16). It comes in 4 foot, 8 foot, and 16 foot diameters.

Q What kind of rpm do you have?

A The rpm is a function of the diameter for a given windspeed. And the rpm I'm talking about on a 4 foot diameter is up to about 800 or so. I'll come to that shortly.

Q How is the power taken off on one of these?

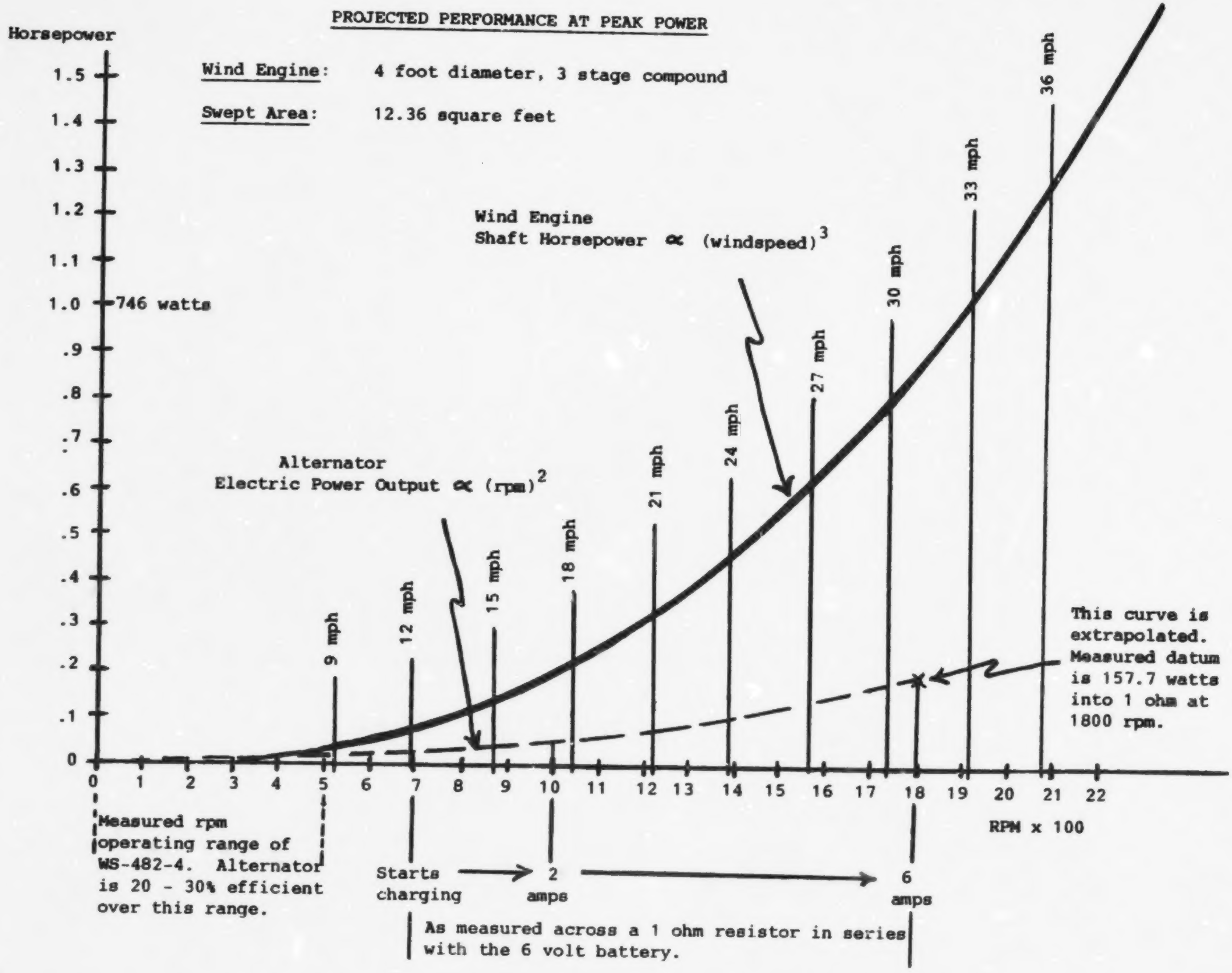
A The power is presently just 3-wires hanging down which looks like your typical telephone wire. It comes off in 3-phase AC. The 16 footer uses slip rings. The 8 footer I don't know what happens.

Q How is the rotor mechanism supported, at the mid-point?

A Yes, near the middle of the generator. The generator sits directly on the support column.

This is the projected performance at peak power for the WS-482-4. I think it is a calculated curve extrapolated from the inventor's dynamometer curves. This shows the rpm at which it is supposed to rotate for peak power. For example, peak shaft power for 21 mph is 0.3 Hp which is at about 1200 rpm. The lower line was obtained from measurements taken with David Platnick's help in the Electrical Technology Department here at Ryerson Polytechnical Institute and this just shows the power output of the alternator for the WS-482-4. Already there were questions before we even got to the Atlantic Wind Test Site as to what the machine was going to produce. Based on this curve, this alternator is way too small for the projected available shaft power. Then again, its torque characteristics may be appropriate for this particular machine because the manufacturer in the States considered this in his choice. The permanent magnet alternator is 'off the shelf' hardware. Not a stepping motor, rather a servo motor, the motor that spins the reels in I.B.M. tape drive units.

PROJECTED PERFORMANCE AT PEAK POWER



Wind Engine: 4 foot diameter, 3 stage compound

Swept Area: 12.36 square feet

Wind Engine
Shaft Horsepower ∝ (windspeed)^3

Alternator
Electric Power Output ∝ (rpm)^2

This curve is extrapolated. Measured datum is 157.7 watts into 1 ohm at 1800 rpm.

Measured rpm operating range of WS-482-4. Alternator is 20 - 30% efficient over this range.

Starts charging → 2 amps → 6 amps

As measured across a 1 ohm resistor in series with the 6 volt battery.

Horsepower
1.5
1.4
1.3
1.2
1.1
1.0
746 watts
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
9 mph
12 mph
15 mph
18 mph
21 mph
24 mph
27 mph
30 mph
33 mph
36 mph
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
RPM x 100

The next figure shows the manufacturer's claim as to the power output. For example, for just under 800 rpm at 15 mph the WS-482-4 should be generating about 14 V and somewhere between 1 - 8 amps. No way. The wire from the alternator, for example, can't handle that kind of current. In our view it is as at best a 6 V battery charger, not a 12 V battery charger. We are measuring an output of 22 watts into a 4.3 ohm resistive load in a 22 mph wind. It is not achieving as high an rpm as projected.

The power we're getting off is sensible for the other power curves that I will show you later.

ATLANTIC WIND TEST SITE

I'm going to take this opportunity to show you a bit about the Atlantic Wind Test Site. We have two, 4 foot diameter Windstar WS-482-4 pre-production models, one of which was taken out to Prince Edward Island in May, 1982. They had a severe snow storm the week before I got there, all the roads were closed. The day that I got there, initially it was quite sunny but became very windy and overcast.

It shows you the cliff, the steep rise that I think, Ken Slater, mentioned when talking about the topography of the land at Tignish. The site with the lighthouse which they had to move because the land is being eroded away. It's not the original lighthouse, that one fell into the Northumberland Straits.

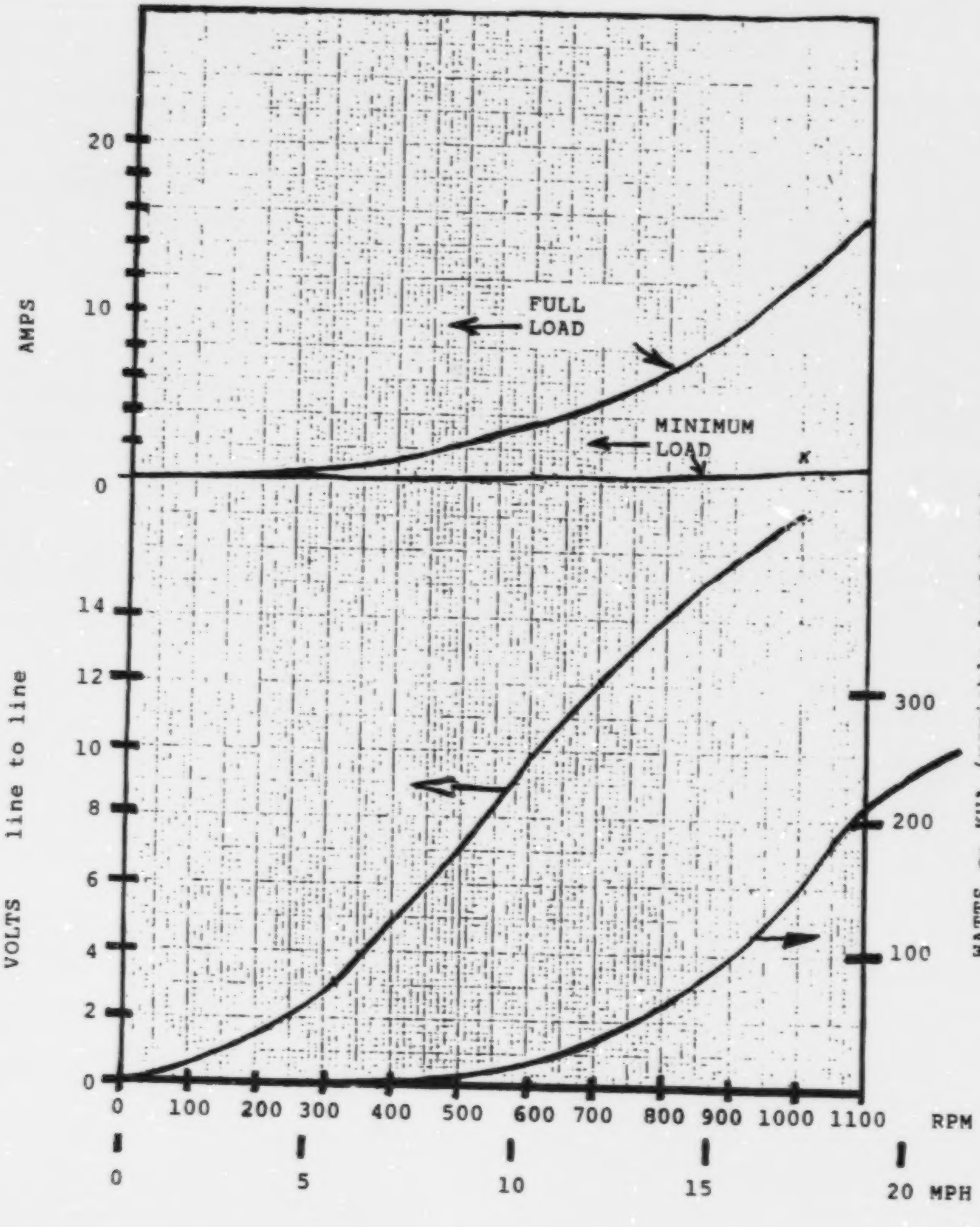
This is their instrumentation processor in a shack. We actually piggybacked our unit onto the processor they had on the DAF Indal 50 kW Darrieus. It's whirring away. This unit collects information from the sensors for voltage and rpm. For the WS-482-4, the rpm was obtained by measuring the frequency of the generator. The instrumentation processor accumulates this data, then is paged periodically by the central processor, to pull the data to main memory then work on it for power production analysis or whatever.

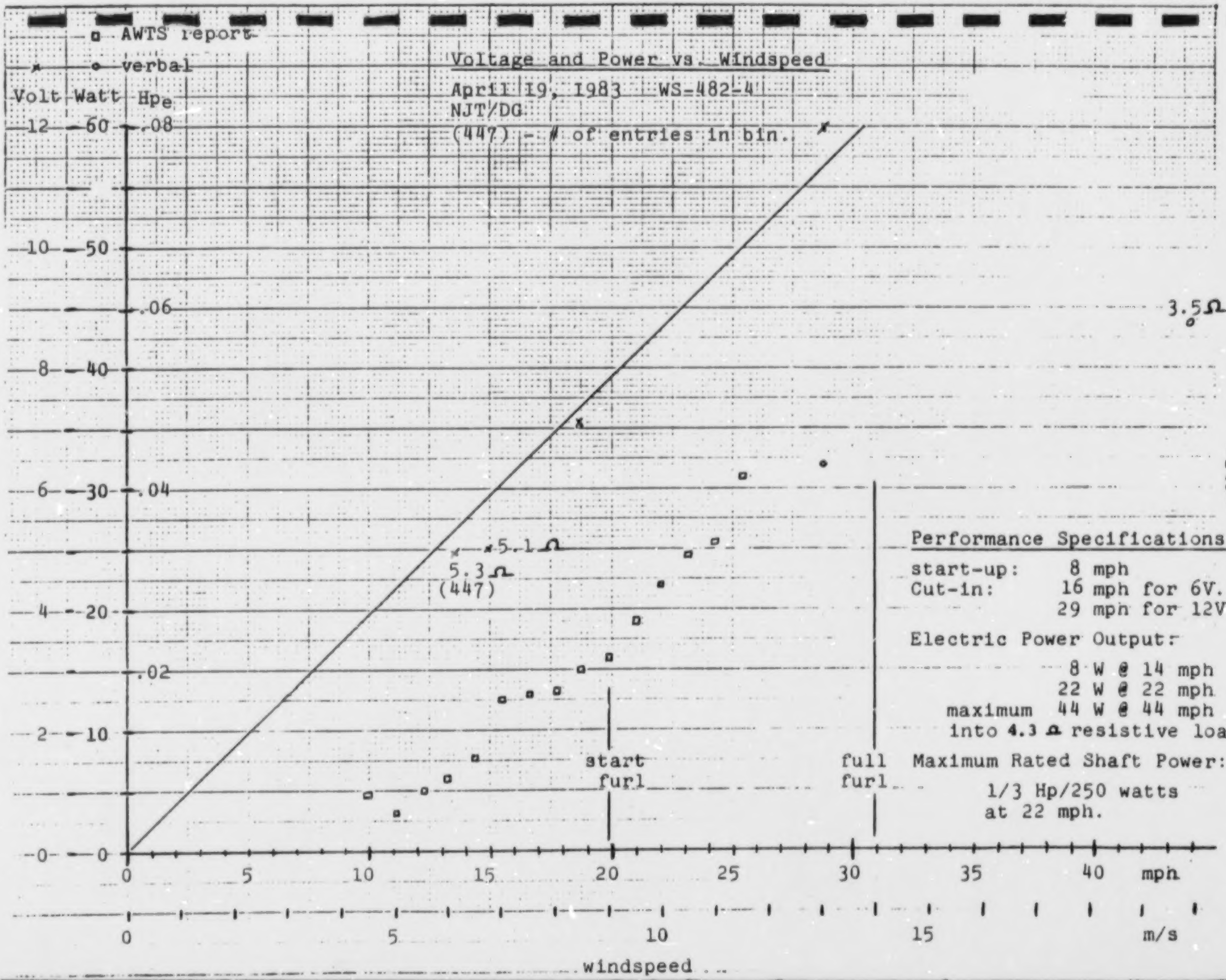
This is a microprocessor in addition to their main system. It's a Texas Instrument of unknown model number. I believe it does most of their number crunching processing. This is the CRT to the Perkin-Elmer, their central processor. Storage is on hard disc with streamer tape back-up. There is a second Perkin-Elmer for mainframe back-up in case something goes. Back-up tapes are made on all of the day's data so they won't lose it. Note the power supply.

Their lab includes an electronics bench for prototyping their own circuit designs. They built a frequency counter measuring circuit then convert the signal to rpm for the WS-482-4. It is fairly well stocked.

WINDSTAR TEST RESULTS

WS-482-4 by manufacturer:
Pawl Inventioneering





Voltage and Power vs. Windspeed

April 19, 1983 WS-482-4
NJT/DG
(447) - # of entries in bin.

Performance Specifications:

start-up: 8 mph
Cut-in: 16 mph for 6V.
29 mph for 12V.

Electric Power Output:

8 W @ 14 mph
22 W @ 22 mph
maximum 44 W @ 44 mph
into 4.3 Ω resistive load

Maximum Rated Shaft Power:

1/3 Hp/250 watts
at 22 mph.

The oscilloscope in another view.

This is their workshop in transition here.

Cleaning it up in part. That is the AWTS technician who installed the unit. The trusty wood stove.

Work bench, grinder and a drill press. If you are a skilled enough craftsman, these are the kinds of tools you would need to make a unit in your own home if you wanted to.

There was a worrisome moment at start-up. After putting it up, the AWTS technician took the rope off to let it fly. As it spun up, it hit an apparent resonance. Turbines generally have to spin through some critical rpm where they shake then settle in again. Well this one did that. The technician was rather close to it while this happened, but without incident. It got passed that and settled down. Here it is installed. You can just see the generator up there.

It was spinning away pretty fast when we put it up. I tried loading and unloading the rotor by just turning the rectifier switch on and off.

Within about one hour after initial installation one of the blades on the innermost diameter, didn't bend backwards but bent forewards by about 45 degrees. Strangest thing, nobody could figure it out, it just bent the wrong way. So what happened was we had to tether it and take it down, straighten it out, then with a mirror and a laser, realign all the blades according to the patent specifications and put it up again.

You can see that the day is pretty overcast. There's a solid wind blowing 22 - 23 mph, so this was going in a fairly sharp wind. Don't know if you can see the bent blade in this shot, you would see it right down in here. Just used a standard box camera for this.

This is the shed where they put the battery and all the instrumentation. Fiber optics cable was run to the other shed and attached to the Darrieus instrumentation processor.

You can see the Darrieus is spinning. That's the one that was on the school in Summerside that Lawrence Schienbein was talking about. You can see the open ocean out there. Definitely a good site to test a windmill. Salt spray.

This is their meteorological tower. I don't know how high it is but this shot definitely gives you a good idea. This is a Dunlite here. Wellington Windpower used to sell a Dunlite or two. They had trouble with the shafts. This particular one used to belong to John Ramsey at his home in Emyvale, P.E.I. which was completely powered by wind. He used Nickel-Cadmium battery storage.

That is a 1 kW Bergey. It was featured on the cover of 'Popular Science' in July, 1982. Apparently they had some troubles with the blades which are laminated then glued together. They've been bending back and separating. So they've had to get a couple of replacement blades. You can see its feathered out of the wind here. the tail is at right angles. I don't know if that problem has been solved yet or what the story is.

This is taken on the run up to Tignish at the Atlantic Wind Test Site. That's an Enertech sitting on a high school just outside of Tignish.

There's an old one. It's a direct drive down to a saw. So you wheel that thing out to the woods on a good windy day when you've chopped all your wood down. Toss it through to cut it up. That was quite a trip just this past spring.

SHELTER VALLEY CENTRE

The second project in the Renewable Dynamics Inc. compound helical test program is at Shelter Valley Centre which is 75 mi. east of Toronto. The Centre is a life style research facility. Most of the work is going into renewable agriculture. This is the garden in 1981 to here.

Site Analysis

These are some shots showing the general site topography. When you have installed a machine, you should climb the tower and take panorama photos of the wind approaches by compass direction. A picture is worth a thousand words in trying to assess where the energy will come from.

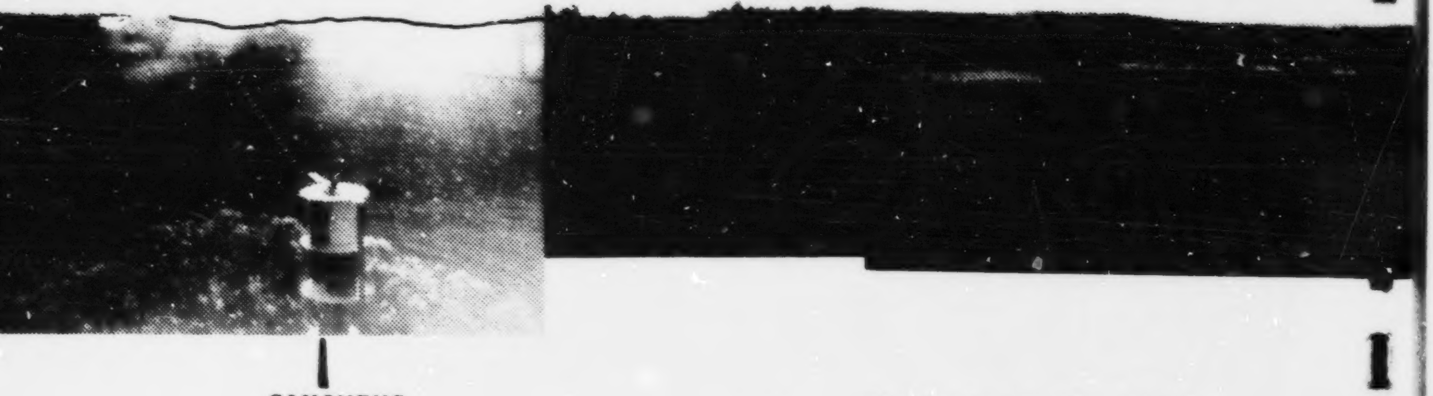
This is west. A nice view, no major obstructions in that direction. One must visualize how the wind is going to roll in off the trees and come up towards you. Whether or not this sort of thing is going to have a significant effect at the height you are at. Definitely looks different when you've seen it with you own eyeballs up there and you are making up your mind. With the picture you can see what you are looking at.

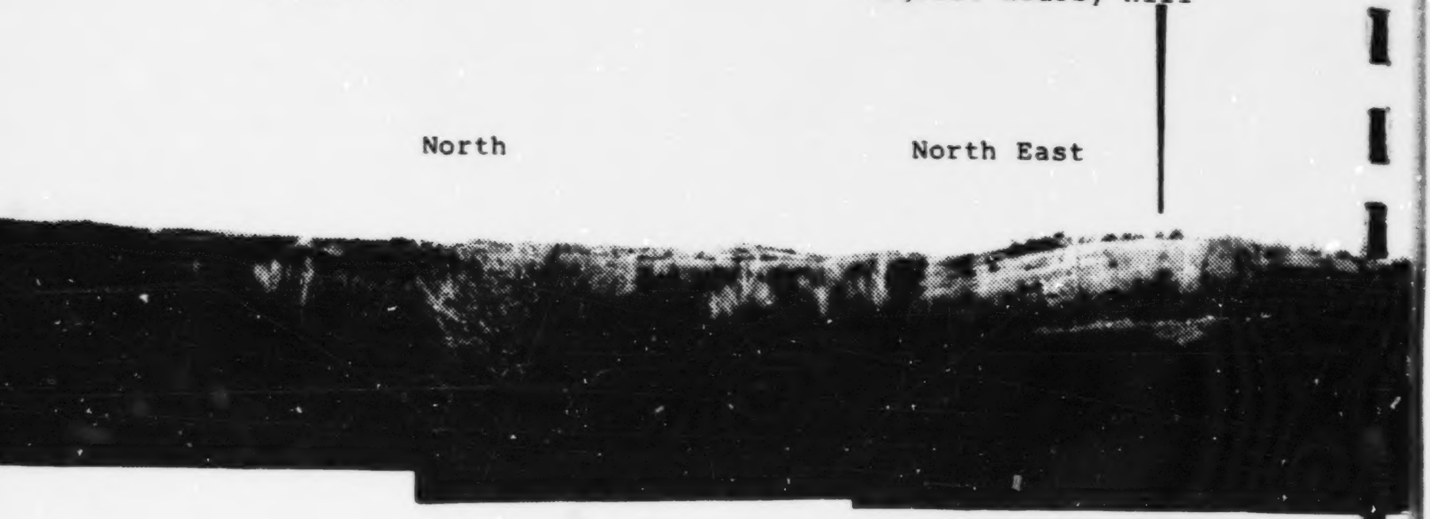
These are the energy quadrants here: West, North West, and North, where most of the energy blows in. Going around the quadrants: this is northwest, north where there is a definite obstruction with the tree. North East, East, there is the Centre's log lodge, the house, two shots of the garden to the South East...South...South West.

Earlier, Paul Leitch was showing where the energy comes from at Kortright. We have two to choose from. Stirling which is farther inland at a valley site and Trenton which we felt had a more appropriate bearing on our situation at Shelter Valley.* We

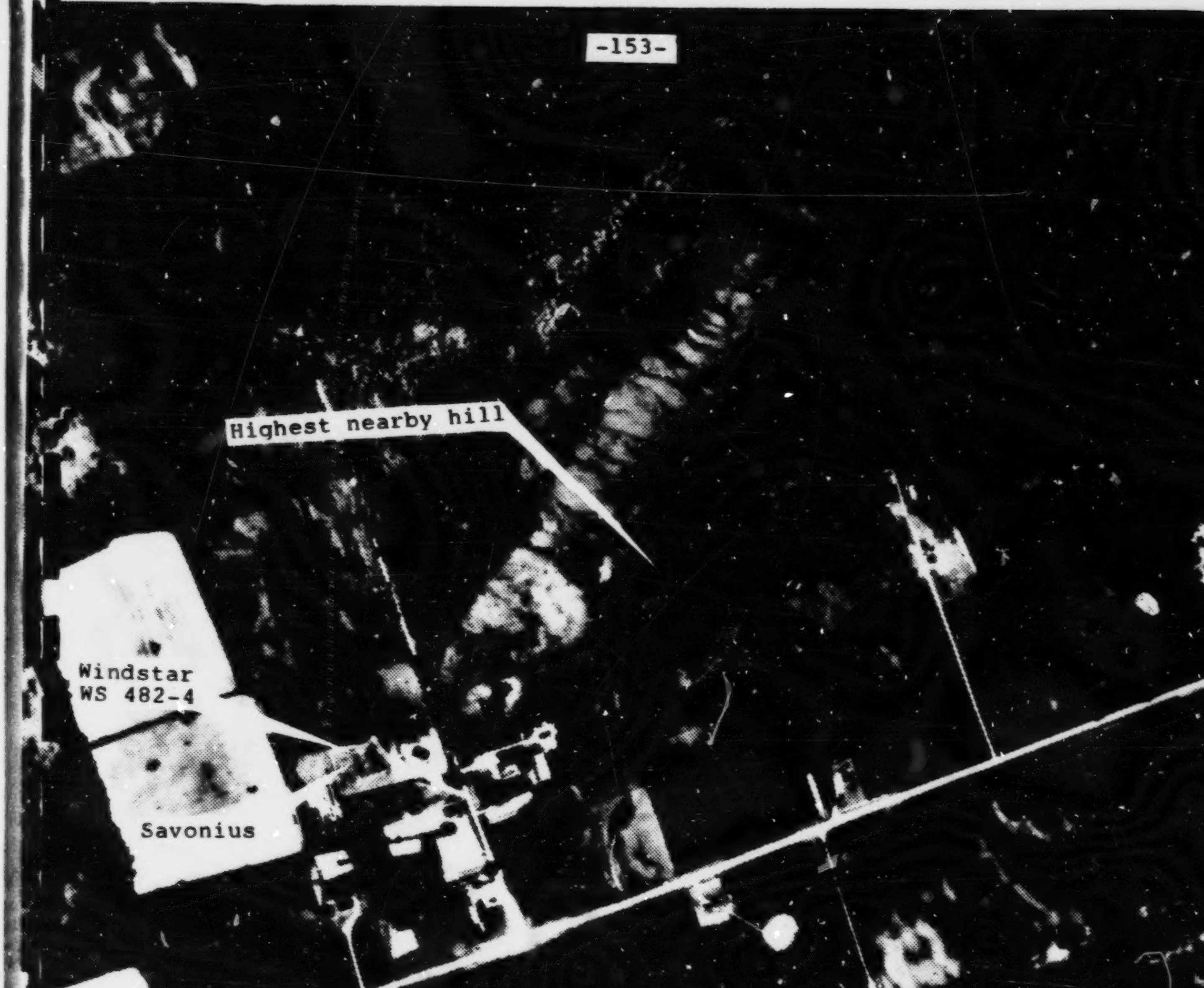
WS-482-4

Shelter Valley Centre


South West
West
North West
SAVONIUS


Highest nearby hill
North
North East

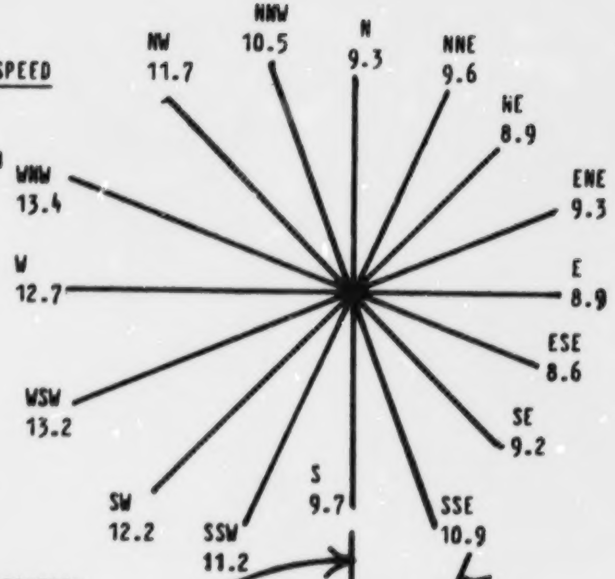
East
South East
South


Highest nearby hill
Windstar
WS 482-4
Savonius
North

TRENTON

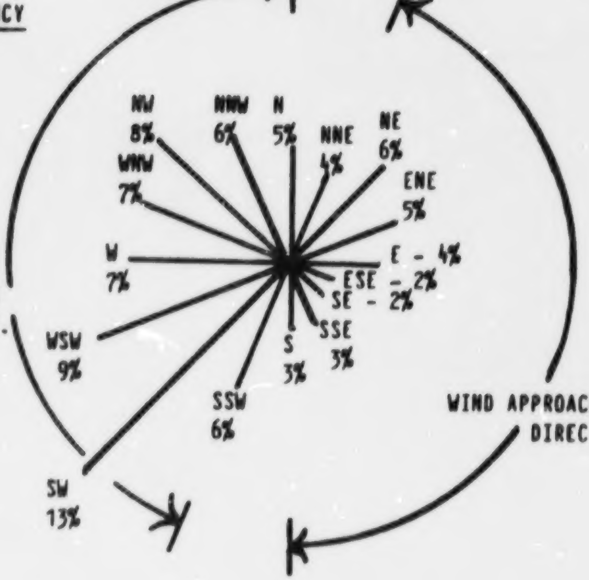
ANNUAL AVERAGE WINDSPEED IN MPH

ANNUAL MEAN = 10 MPH



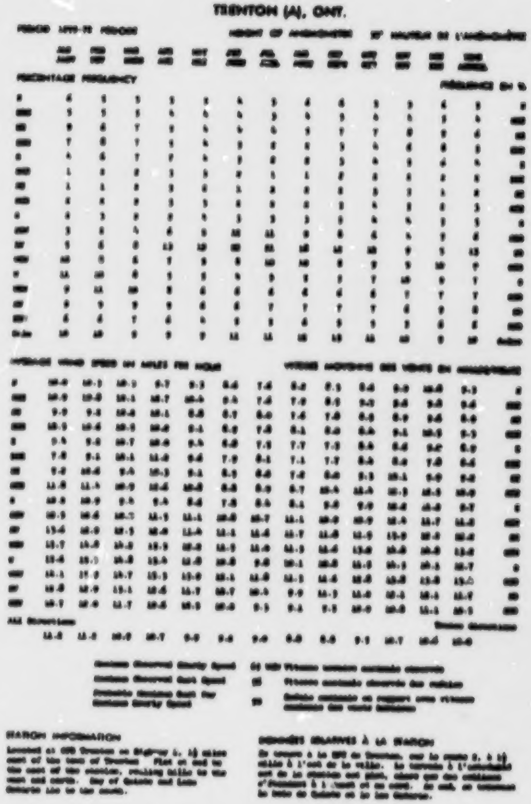
ANNUAL PERCENTAGE FREQUENCY

CALM = 10%



WIND APPROACHES FROM THIS DIRECTION 61% OF THE TIME.

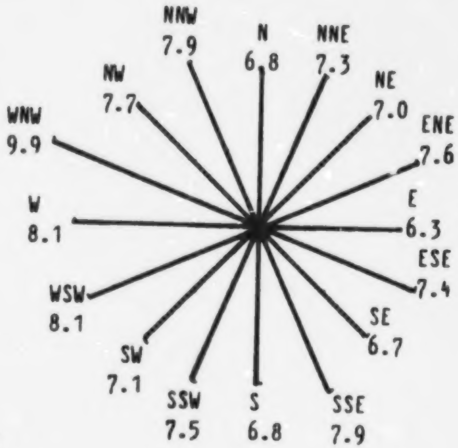
WIND APPROACHES FROM THIS COMPASS DIRECTION 29% OF THE TIME.



TRENTON (A), ONT.

STIRLING

ANNUAL AVERAGE WINDSPEED IN MPH

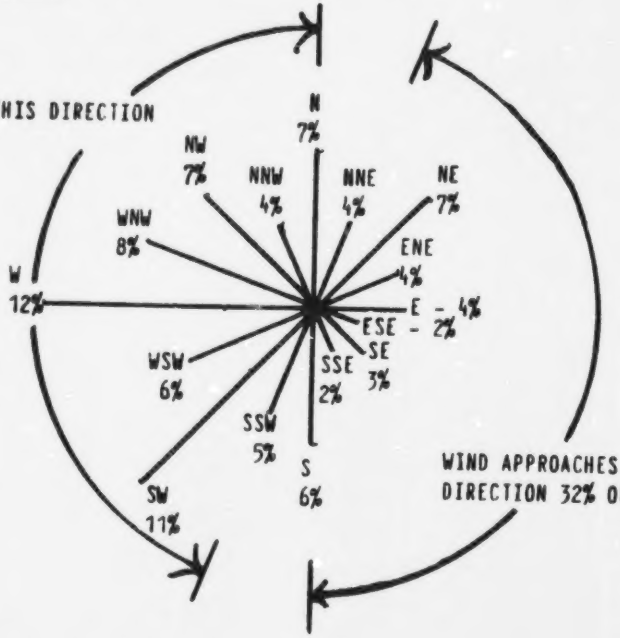

N 6.8
NNE 7.3
NE 7.0
ENE 7.6
E 6.3
ESE 7.4
SE 6.7
SSE 7.9
S 6.8
SSW 7.5
SW 7.1
WSW 8.1
W 8.1
WNW 9.9
NW 7.7
NNW 7.9

ANNUAL MEAN = 7.1 MPH

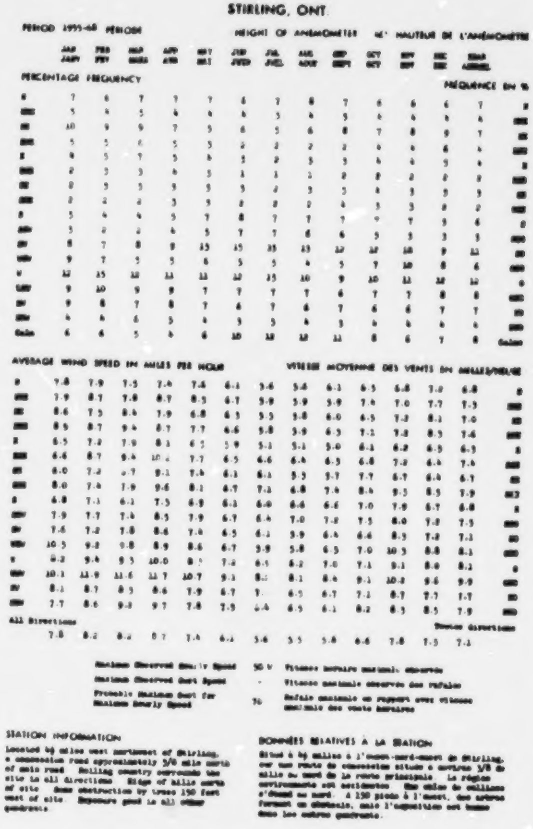
ANNUAL PERCENTAGE FREQUENCY

WIND APPROACHES FROM THIS DIRECTION 60% OF THE TIME.

CALM = 8%


N 7%
NNE 4%
NE 7%
ENE 4%
E - 4%
ESE - 2%
SE 3%
SSE 2%
S 6%
SSW 5%
SW 11%
WSW 6%
W 12%
WNW 8%
NW 7%
NNW 4%

WIND APPROACHES FROM THIS COMPASS DIRECTION 32% OF THE TIME.



STIRLING, ONT.

PERCENTAGE FREQUENCY

AVERAGE WIND SPEED IN MILES PER HOUR

VITESSE MOYENNE DES VENTS EN MILLES/HEURE

STATION INFORMATION

DONNÉES RELATIVES À LA STATION

consider ourselves closer to a lake site than an inland site. We are only about 10 miles inland from the shore of Lake Ontario. So there is still an influence from the lake. However it shows a lot of the energy here at Trenton coming in from the lake down here. Keep in mind where Trenton is situated to see why there is a big pull down there. Stirling shows it from the other side where we generally expect it.

This is only useful in going back to considering the slides. where the tree is relative to the windmill for example. Or. intentionally locate it to take advantage of landform wind speed augmentation where most of the energy is. If we run through the slides once more. you'll see that there is really nothing blocking to the North West. it's not to bad to the North and it's really nice to the south but there is not very much energy there.

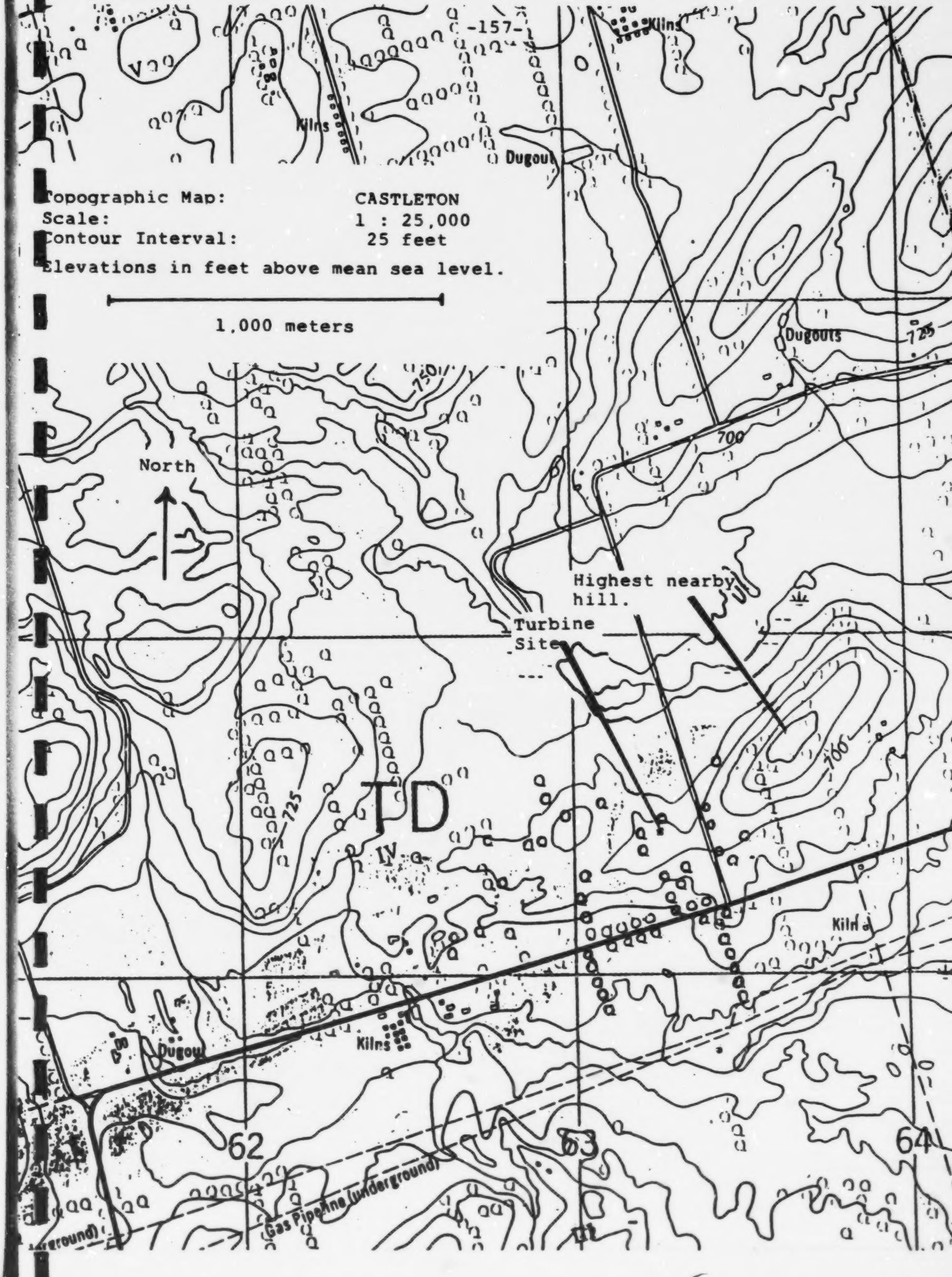
Q What's the energy terms?

A I don't have that at my fingertips but my recollection is that it is pretty crummy. You are talking about maybe 9 mph or so at Trenton and maybe something like 7 at Stirling.

Stirling is pretty crummy. This will show you the topography a bit better. Here is Lake Ontario down here. This is the hand waving stuff of the wind business. because you don't have a rule that says you do all these steps and there is your answer. There is Trenton and the lake below left. Stirling north of Trenton and our site on the far left. The shoreline runs roughly like this. I think the Shelter Valley Centre site is subject to the water influence from Lake Ontario. The water is closest to the South which affects the shape of the Trenton 'average wind speed by compass direction' distribution. Notice the 'bulge' in windspeeds points directly towards the shortest distance to Lake Ontario from Trenton. There is still a lot to the North West but there seems to have been a shift from say the Stirling distribution and I think it is the water influence.

You have to get a topographic map to see how your site fits into an overall picture. This is where the site is here for the windmill. The windmill is located approximately here. This is one of the best areas over here for a nice big turbine. Note the other hill over here which you could see in the slides.

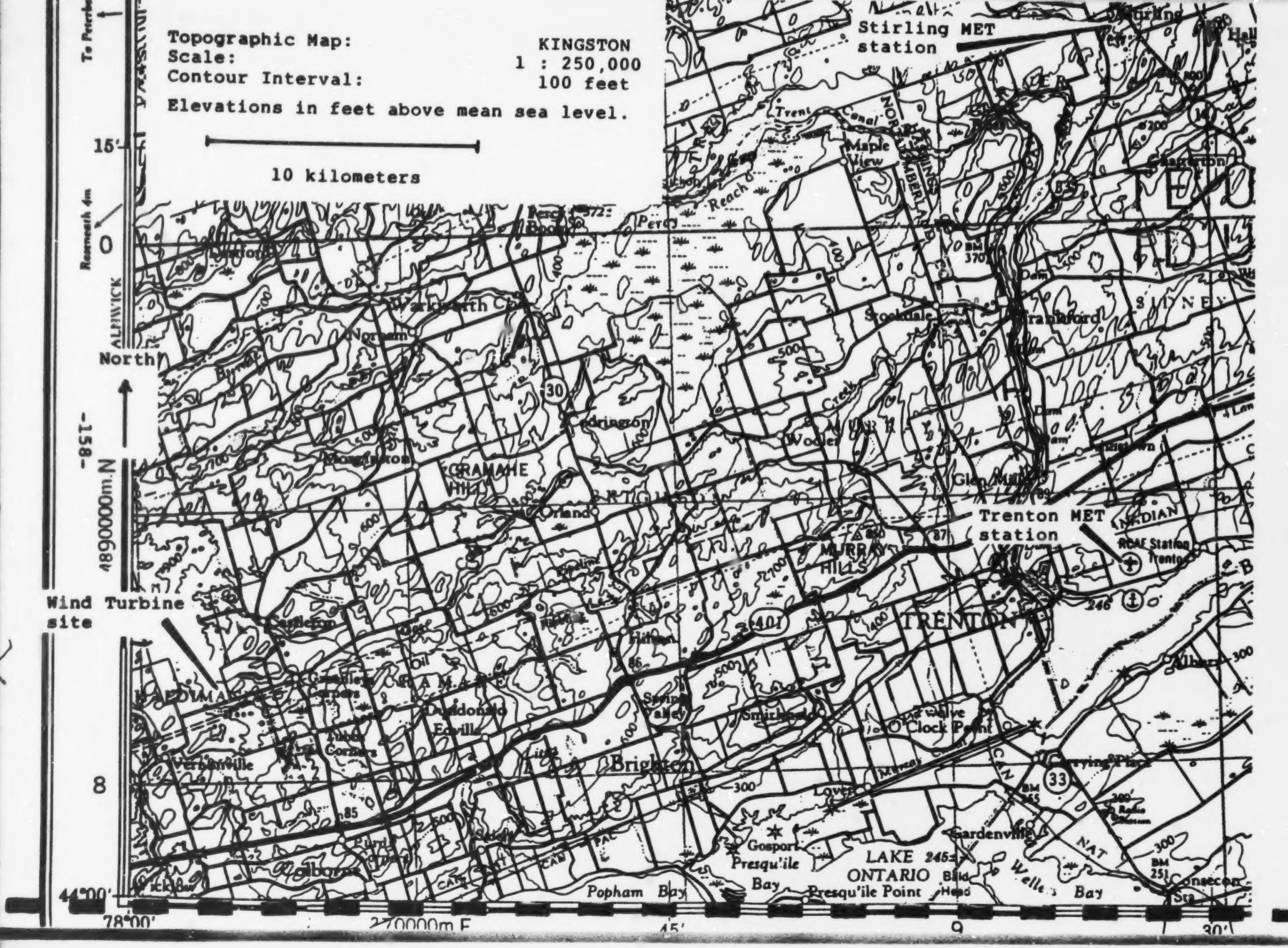
A geography graduate student at the University of Toronto came up with a technique for evaluating a site's best location for wind energy augmentation through terrain speed-up. He scratch-built cup anemometers from L'EGGS panty-hose cups. He took a long straight wire. cut it to equal 6" lengths. threaded it. and put the cups on it. He attached three of these wire/cup arrangements to a straight revolution counter like a bicycle odometer. then mounted them on top of tripods at 1 meter above the ground surface. He came out to the hill at Shelter Valley Centre when the wind was coming in from the west and positioned these anemometer/tripods in a grid arrangement over a period of 20 min.



Topographic Map: CASTLETON
Scale: 1 : 25,000
Contour Interval: 25 feet
Elevations in feet above mean sea level.

1,000 meters

North
Highest nearby hill.
Turbine Site
Kilns
Dugout
Dugouts
Kiln
750
725
700
TD
IV
62
63
64
Gas Pipeline (underground)

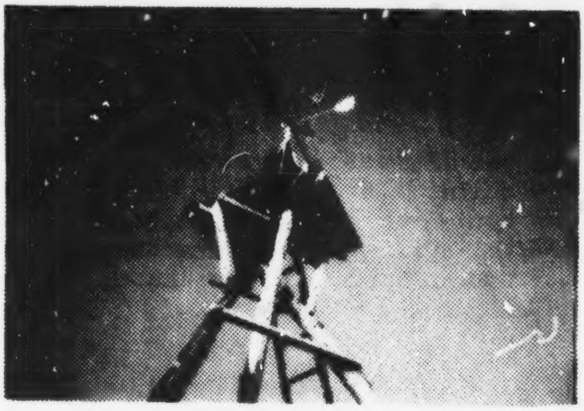

Topographic Map: KINGSTON
Scale: 1 : 250,000
Contour Interval: 100 feet
Elevations in feet above mean sea level.
10 kilometers
Stirling MET station
Trenton MET station
Wind Turbine site
North
4890000m.N
270000m.E
15'
0
8
9
44°00'
78°00'
45'
30'
Warkworth
Codrington
Brighton
Trenton
Murray Hills
Gramahe Hill
Colborne
Lake Ontario
Presqu'ile Bay
Popham Bay
Wellers Bay
Consecon

or so. These were left up for 3 or 4 hours in a good stiff wind from the prevailing energy direction to see where most of the counts showed up which indicated where to locate the windmill. You should of course be doing that for when the wind comes from each quadrant with particular attention being paid to your energy winds.

To review the site slides again with fresh eyes: South West, West, East. There is the peak of the largest hill in the area to orient you relative to the topographic map. Notice particularly its shape, a nice rounded shape that causes the compression of the air near the crest. There is wind speed augmentation at that point to the extent of doubling or even tripling the amount of available energy. If you see some property like that, perhaps buy it.

*****Tape Ends*****

Windstar WS-482-4 Installation



This is the WS-482-4 installed at Shelter Valley Centre. The red box on the stub tower houses the rectifier. Three wires come directly from the generator and just dangle out the bottom of the rotor support column and go into a hole in the side of the red box. We just untwist it if it gets too twisted. To minimize losses there are no slip rings.

The design and construction procedure is simple. Three posts were cut down in the local cedar swamp. The rest of the lumber was obtained in a lumber yard. First an A-frame was built on the ground, then the platform mounted on the apex. It was carried by six men as one big unit from the workshop around the garden via a fallow field to the site. The tower design utilizes a centre 'scissor' pole that rotates on a length of wood dowelling (an old handle from a broken shovel) near the apex of the A-frame. The wood dowel was inserted through holes drilled through the centre 'scissor' pole and the two brace poles of the A-frame.

The tower was erected by first lifting the apex of the A-frame off the ground to insert the wood dowelling through the frame poles and the single 'scissor' pole with, the 'scissor' pole running from the dowel at the A-frame apex in the direction away from the A-frame base. The pole was then walked up while the tractor pulled up the A-frame. It may be possible to push this platform up using the 'scissor' pole only without the aid of a tractor. As the 'scissor' pole pivots about the dowel, the end of the 'scissor' pole fits nicely between two 2" x 6" cross braces on the underside of the platform. After brace crosspieces were attached to the tower base, someone climbed up the ladder to nail straight through the platform cross braces into the end of the 'scissor' pole to complete the tower.

Note that there is a bit of a strain apparent on the wood dowel hinge piece in this view.

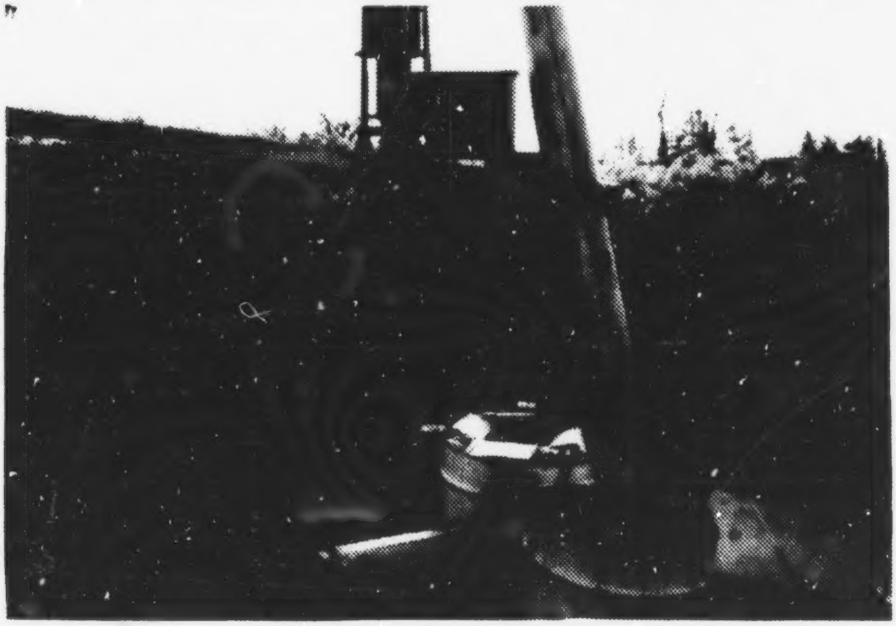
I've stood on the top, it is probably safe for one person at a time. It has a bit of life in it, but not too much. You don't feel like dancing, but you do feel reasonably secure.

The 'N' on the underside indicates which way is north. Note also the blade detail and the generator itself.

It is a fun climb up the ladder. A safety feature is the cutting of a definite notch in the platform so the ladder won't shift. The ladder is lashed right to the top of the tripod tower, so it stays up all the time. One feels comfortable going up and down that by themselves. You can bounce the ladder against the tower, it doesn't shift at all.

Q How tall is it?

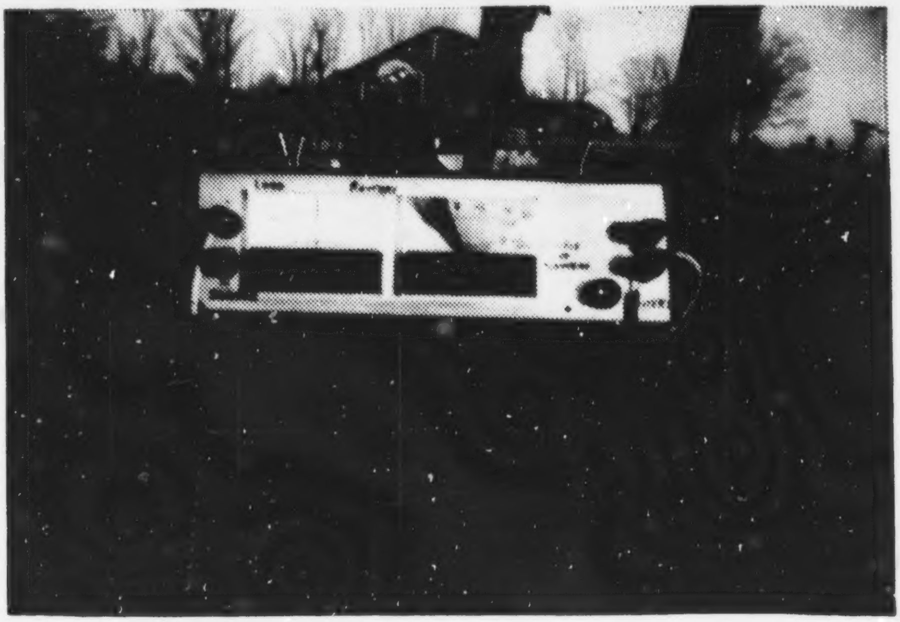
A It is 20 feet to the platform. It is probably about 28 feet to the hub height which is close to the standard anemometer height and the height of the machine at the Atlantic Wind Test Site.



Some detail of the legs. Note that we have driven stakes in and tied it down, so the wind won't tip it over. There's a cross brace to maintain the base spacing. We just cut two 45 gallon oil drums in half, filled them with gravel and then just set it straight on top of it. The idea being that gravel would promote drainage so the wood wouldn't rot. Hopefully it can just sit there forever. This is the other leg.

The fourth oil drum half we turned into a battery case. I just cut a hole out of the side and screwed two pieces of wood together and drilled through the wood for the wires to enter. The red top there is just screwed right onto the top and it is packed with insulation to try and keep it warm. The best thing to do though would be to berm it or sink it into the ground for temperature stabilization.

There is the all-weather box up here, because the control/monitor box that I have is not weather-proof. In order not to open it in the winter time, a piece of plastic was put on the door to permit reading the meters to determine the state of the battery charge or if there is any voltage/current from the wind.



Here is some meter detail. Notice the colours on the face of the voltmeter. The green band is where you want the battery voltage to sit. By flipping the voltmeter switch to battery, you can see right away whether you've got a problem or not. The current meter is supposed to show current into or out of the battery. This thing's been running for about a month and a half and I haven't seen that needle budge, even though I know there is voltage coming off the wind machine.

Some of the options are:

- the voltmeter either reads the voltage off the machine or the voltage on the battery.

- the wind machine can be loaded with the battery or a straight resistive load containing a 1 Ohm to to 30 Ohm variable resistor. in series with a 12 V car headlight lamp and a 1 Ohm 20 W resistor mounted on the back of the monitor box.

One can change the loading while it is running to observe, for example, changes in output voltage and rotor rpm with changes in the loading. However, I could not detect any current flow on the 2-way meter when the turbine's output was plugged into the battery. I was certainly able to get the light bulb to glow brightly in reasonable winds. There is electricity there, but it needs more work in order to make it run properly.

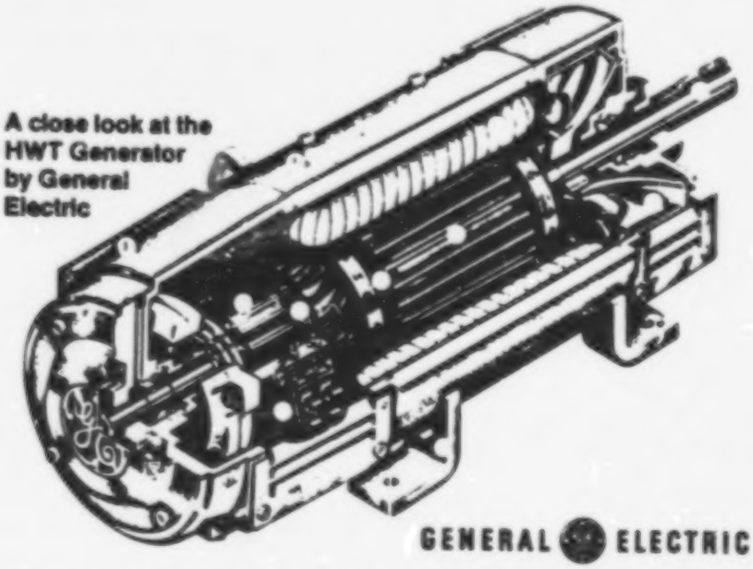
This unit was allowed to operate unattended for 10 months and was finally tethered in September, 1983 because the blade welds had loosened suggesting an unsafe condition.

It was noted that over this period a constant voltage, therefore charge, was maintained on the battery. A production machine made to appropriate standards of quality control would be useful for maintaining a float charge on a battery for periodic low drains, e.g. an electric cattle fence.

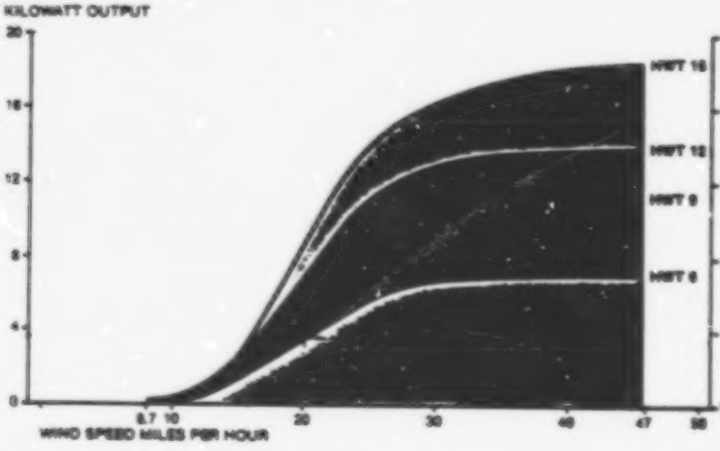
FIELD EXPERIENCE

Environmental Energies, Inc.

In the late 1970's, this company built the HWT 9, a 20 foot diameter, proof of concept, helical wind engine. This four blade-pair (8 bladed) configuration was rated at 9 kW in a 25 mph wind. A General Electric generator custom designed for wind turbines was used in this prototype.



It operated for about one month after which time it threw a blade. This was attributed to quality control. The blades were trial fabricated with off-the-shelf angle iron and steel sheet metal. This company has not constructed another prototype since.



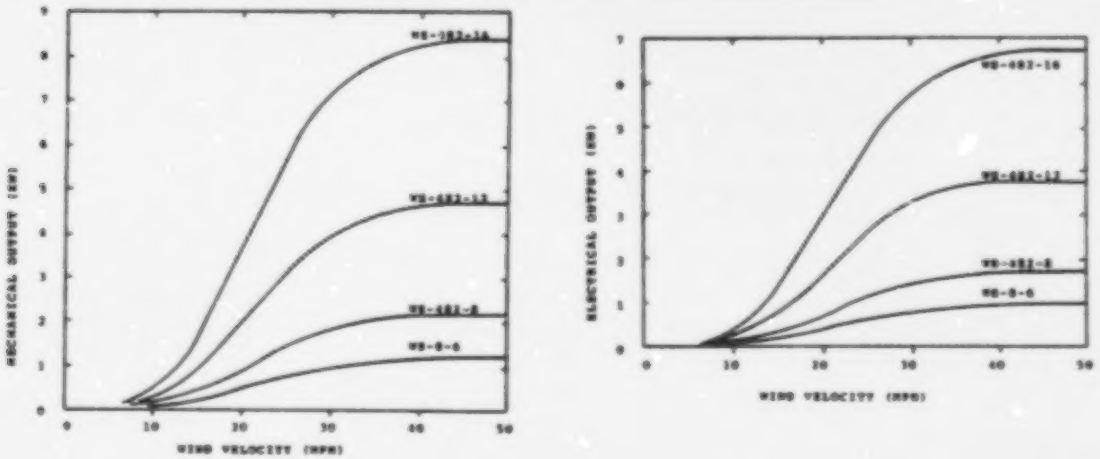
MODEL NUMBER	RATED OUTPUT	CUT IN WIND	CUT OUT WIND	RATING SPEED	BLADE DIAMETER	*AVERAGE OUTPUT KWH/YR
HWT 15	15KW	8.7MPH 3.9M/S	47MPH 21M/S	25MPH 11M/S	24'	23,477
HWT 12	12KW	8.7MPH 3.9M/S	47MPH 21M/S	25MPH 11M/S	22'	18,760
HWT 9	9KW	8.7MPH 3.9M/S	47MPH 21M/S	25MPH 11M/S	20'	14,085
HWT 6	6KW	8.7MPH 3.9M/S	47MPH 21M/S	25MPH 11M/S	16'	9,390

Prior to blade failure, preliminary measurements indicated that the rotor was performing up to expectations. Prototype hardware in the helical wind engine development program has since been fabricated with stainless steel or fiberglass reinforced, aircraft-grade epoxy. In addition, it is recommended that wood may not be a suitable blade material for helical wind engine diameters larger than six feet.

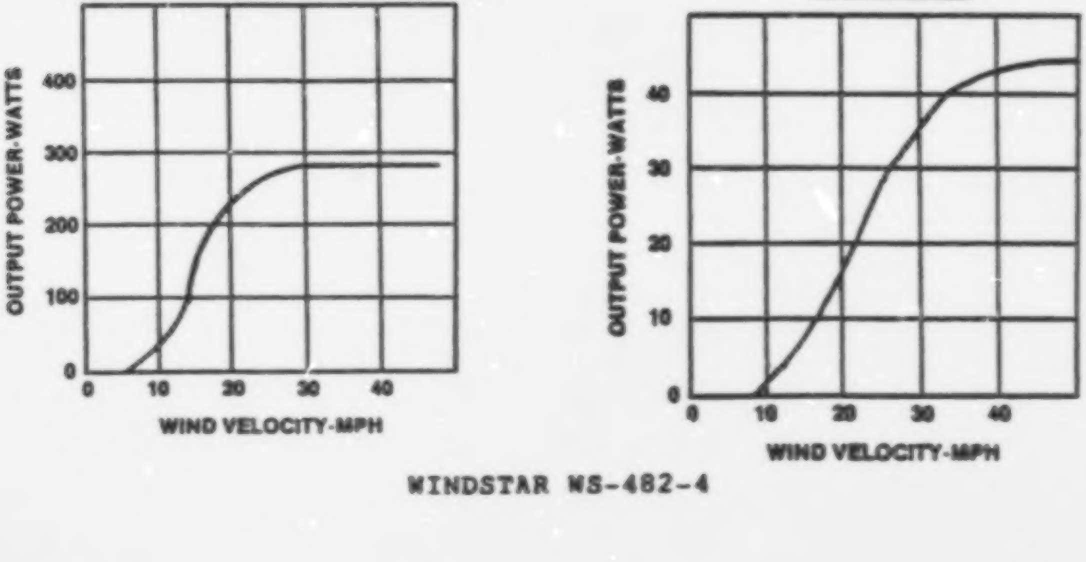
Windstar

Up until mid-1983, there were three sizes of Windstar compound helical wind engines available. These all-stainless steel construction pre-production prototypes were:

MANUFACTURER'S OUTPUT POWER CURVES

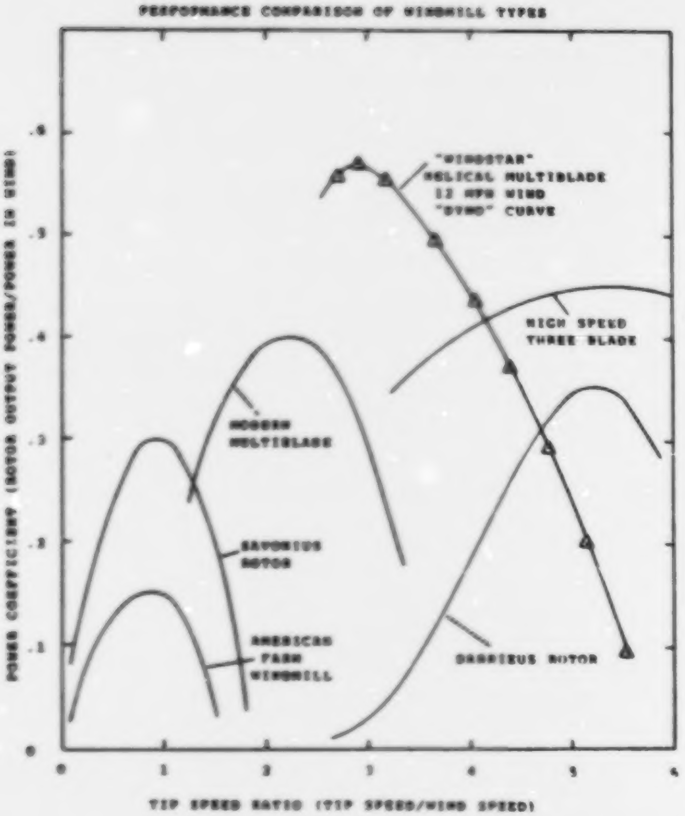


- the WS-482-4, 4 feet in diameter, three phase permanent magnet alternator rated at 250 W in a 25 mph wind. AWTS test measured output was 31 W in a 25 mph wind.

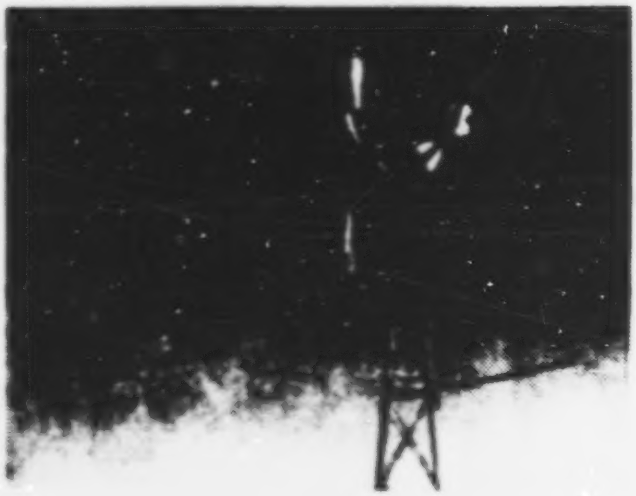

MANUFACTURER'S LITERATURE

AWTS TEST

WINDSTAR WS-482-4



- the WS-482-8, 8 feet in diameter, unrated.
- the WS-482-16, 16 feet in diameter, three phase permanent magnet Zephyr Wind Dynamo Co. alternator rated at 3.5 kW in a 22 mph wind and 1.1 kW in a 14 mph wind.



As of 1981, there may have been as many as fourteen WS-482-4's, two WS-482-8's, and ten WS-482-16's in the field. Of particular interest is the field experience with the WS-482-16.

WS-482-16

A number of modes of failure occurred with pre-production prototypes of this particular unit.

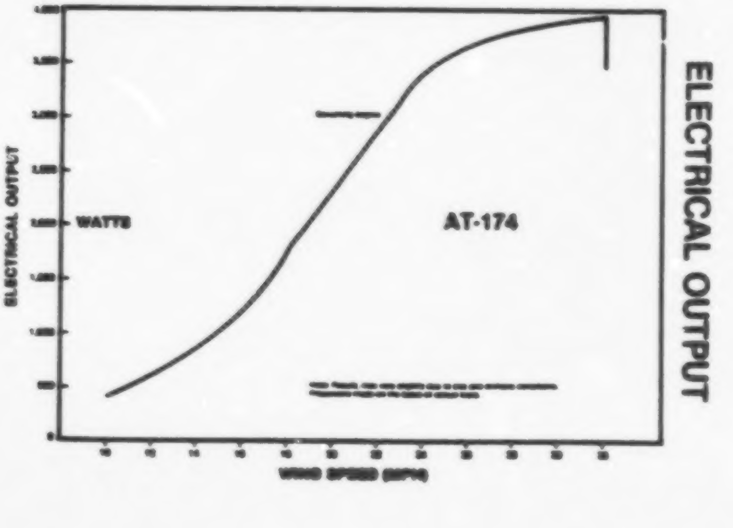
Initially there were problems with alternator cogging which the Windstar manufacturer had to solve in cooperation with the alternator manufacturer then retrofit field units. Alternators also burned out because they were undersized for loading the machine down.

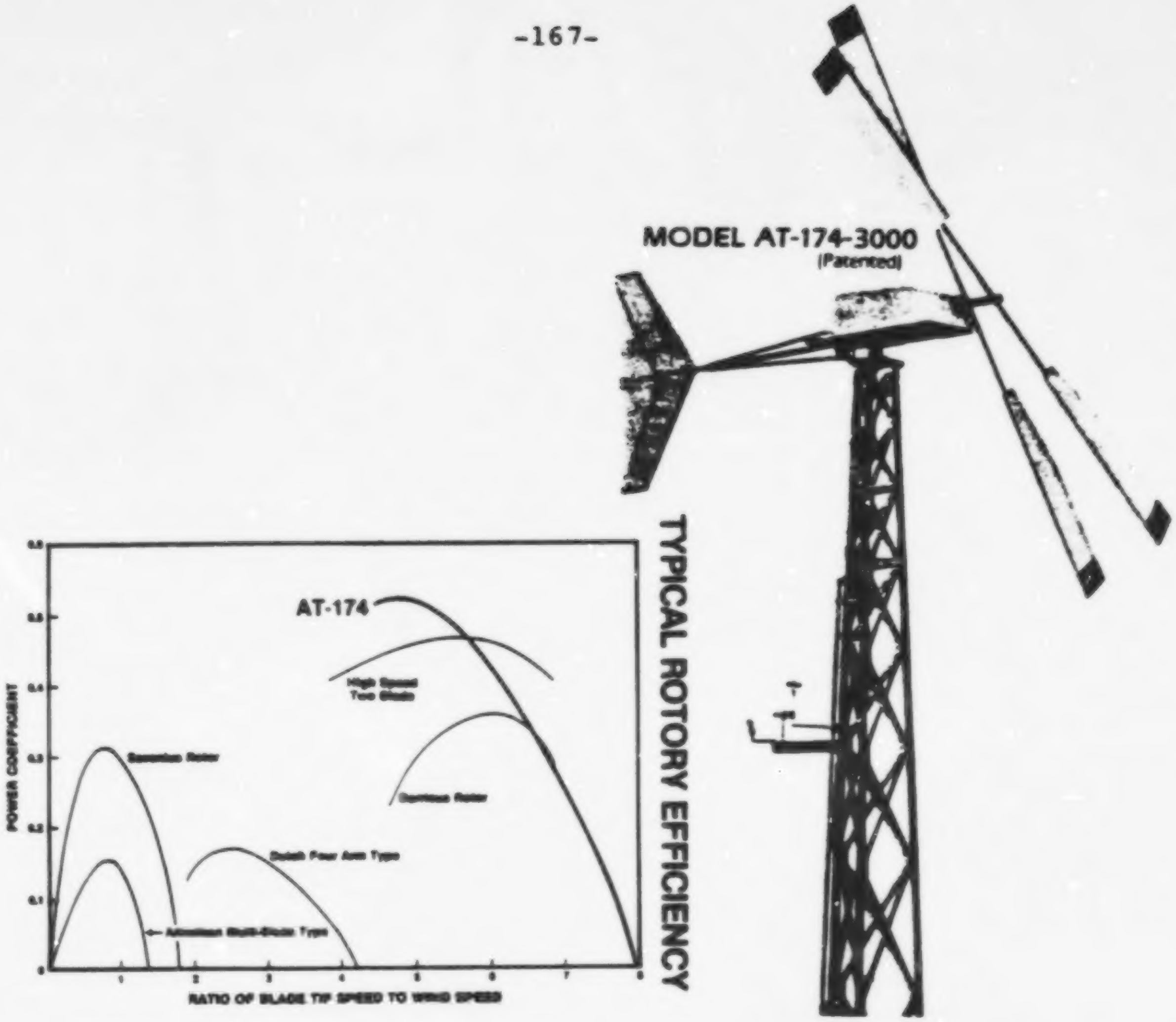
Wind shaft failures occured where the aft rotor hub-tube connected to the alternator stub shaft. The tubing was not strong enough to handle the stress of the wind loading on the large outer diameter fan.

The alternator support column has bent back in high winds (which also happened to both of the WS-482-4 prototypes tested by Renewable Dynamics Inc.). The manufacturer modified the steering mechanism design to considerably shorten the length of the WS-482-16 alternator support post to overcome this problem. In one case a WS-482-16 owner modified his unit by deliberately bending the rotor post back to give the wind shaft an angle of 6 degrees to better handle wind shear. However, in an exceptionally heavy storm a wind gust lifted the steering mechanism which caught the outermost diameter blade-pair. There was a six inch deep gouge in the blade and the spar had bent but the rotor maintained its structural integrity.

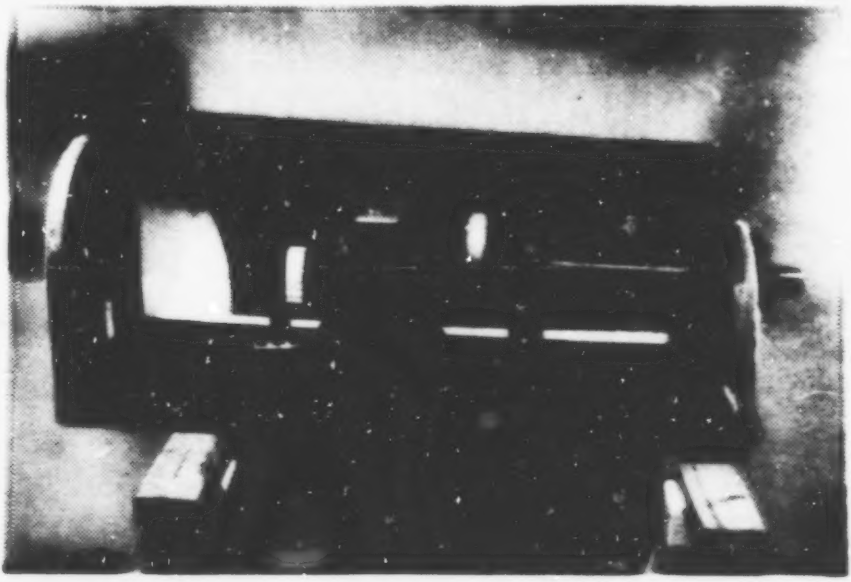
I am not aware of any instances of blade throw with this design.

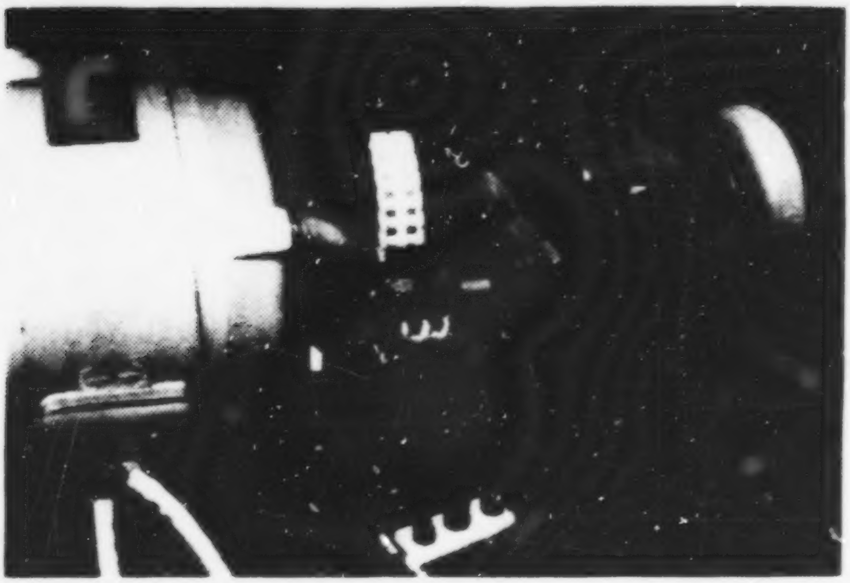
Air-Track Marketing





The model AT-174-3000 has been available on the market since 1983. There are several production prototypes in the field. The nearest installation which I have visited is a Gemini synchronous inverter application with 4 kW heating dump load. It is located outside Buffalo, New York. It is a four bladed (two blade-pair) helical wind engine that is 17 feet in diameter and rated at 3 kW in a 24 mph wind. The blades are an aircraft fiberglass/epoxy composite.





Considerable thought and work has gone into the design of the drive chain. The wind shaft has its own heavy duty tapered roller bearings resting on pillow blocks. The wind shaft is connected to the gearbox by an elastomer element and the gearbox is connected to the alternator by a plastic sprocket coupling. The three phase, permanent magnet, brushless Georator alternator (model 36-217) is rated at 3 kVA at 1600 rpm although it is capable of delivering 6 kW, continuous duty. The 8.85 : 1 speed increasing gearbox is a Morse 351 H. with a modified gear alloy to give a 4.8 Hp rating. The steering mechanism is a spring loaded tail vane with the wind shaft offset approximately 6" from the centre of pivot on the tower. There is a yaw turning force associated with the offset wind shaft which eventually overcomes the spring tension allowing the tail to fold to a position perpendicular to the rotor's plane of rotation.

Initial shakedown experience indicated a need to adjust the tail vane spring tension and the Gemini synchronous inverter to achieve rated power. There was also some question as to the effect of local vegetation and topography on the unit's output. Also, in this particular helical configuration, it was found that cyclic rotor loading was loosening the hub assembly from the wind shaft. Consequently, the blade-pairs have been set at right angles to each other to overcome this problem. No significant loss of power has been noted after this design modification.

Safety

To my knowledge, no significant 'lost time' injury or property damage has occured to personnel or the public during normal or abnormal operation and maintenance of the equipment during the ten year research, test and development program to date.

DESIGN DISADVANTAGES

The greater number of blades in the helical wind engine over standard designs adds both to the overall cost and the weight at the top of the tower. Greater angular momentum in the rotor may be more of a challenge to brake. Reduction in blade cost through mass production may or may not compensate for the added cost in terms of more blades per unit. Weight reductions may be achieved with epoxy composite blades.

When the helical rotor is turned out of the wind, it presents a larger blockage area to the wind than a 'flat plane' rotor. This may result in a tower's design wind loading limit being reached at a relatively lower windspeed.

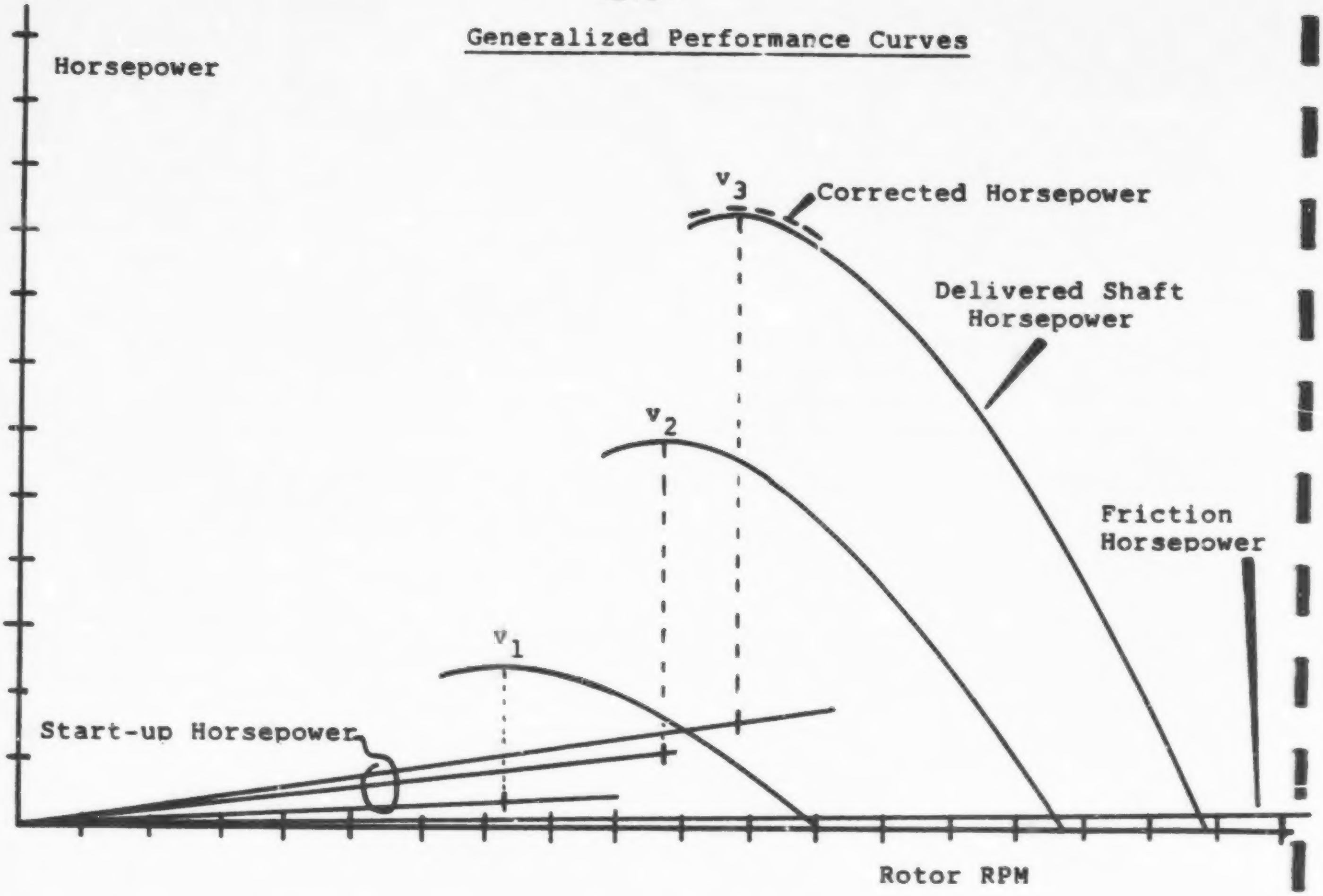
It is difficult to predict the 'flying' stability of this design in modular stacked arrays. It is at least as challenging as a utility designing and installing extra-high voltage transmission towers, say, in terms of damping conductor gallop in high winds.

DESIGN ISSUES

The key to this design is the understanding of the 'magic' that happens around Reynold's Numbers of, say, 100,000 or greater where in aerodynamic theory, the lift coefficient becomes significantly greater than the drag coefficient for smooth airfoils. The windspeed at which an airfoil's Reynold's Number will pass 100,000 is dependent on the chord of the airfoil and the tip-speed ratio of the machine. The brake/drag effect of the triangular shaped airfoil may 'take over' at too low a windspeed for the blade chord of machines above a certain diameter and those machines may have an unacceptable efficiency. This may be overcome with modifications in airfoil design dependent on the increase in rotor diameter.

This figure illustrates output power vs. rpm. Note that there is no tail on the left hand side of the peak power curve, rather a line which indicates start-up horsepower, i.e. the power output by the rotor when it starts under load. The inventor claimed that based on the output results of the Windstar WS-482-4 test at AWTS, P.E.I., the rotor never got above start-up horsepower. In order to achieve the design's peak potential efficiency, the solution may be either an in-line clutch such as a Salisbury clutch (even though it operates at too high an rpm), or an externally excited generator with wind speed and wind shaft rpm sensors. In the latter case, an electronic control mechanism would be necessary to turn on the field current when the wind shaft rpm gets above the peak power rpm for a given, averaged wind speed. Another option on the electronic control mechanism may be to momentarily motor the machine up to peak power rpm at start-up. This problem is a typical one in the wind business which sometimes sees large HAWT's employing overrunning clutches in the drive train or microprocessor control.

Generalized Performance Curves



Measured Performance Data

4-Blade Helical Wind Engine, U.S. Patents: '4,065,225' & '4,171,929'
18" diameter, Swept Area: 1.5708 sq. ft., brass blades
This test was made in a free air stream 18" in diameter.

	v_3	v_2	v_1
	12 mph	10 mph	8 mph
Efficiency at Peak Horsepower	51.8%	57.2%	47.5%
Peak Measured Shaft Horsepower	.00935	.00590	.00245
RPM at Peak Power	1,080	970	730
Tip-speed Ratio at Max. Horsepower	4.82	5.19	4.88
Torque Ratio: $\frac{\text{Peak Horsepower}}{\text{Start-up Horsepower}}$	5.81	4.91	6.0
Reynold's Number at the tip	56,114	50,351	37,875

Reynold's Number: R_e = 6350xUxl, where U = tip-speed x windspeed in fps.
l = chord length in feet
1 mph = 1.4667 fps

In addition, all production units must be fitted with a disc brake that can be manually activated from the ground and a positive bolt-lock mechanism to lock it during maintenance activity.

COST PROJECTIONS - MASS PRODUCTION

Some cost projections have been made by the inventor based on his experience as a senior S.A.E. production engineer with the Ford Motor Company. The manufacturing costs would be estimated at the going 'cost per pound' to shape similar material to automotive quality control standards and at a quantity of material throughput necessary to achieve that industry's level of mass production. This level of production could only be applied to that iteration of the design which is deemed to be sufficiently technically mature.

In February 1980, the inventor estimated that an 80 foot diameter, 3-stage compound helical could be installed for $50,000. - $60,000. each, in multi-unit arrays. Such a unit was estimated to be capable of producing 60 kW-h each hour in Detroit, Michigan's average windspeed and up to 300 kW in a 36 mph wind speed. All components in such an array are designed to be transported on conventional highway equipment. The supporting towers and cables offer protection from lightning. The array could be designed with a minimum durability objective of fifty years. A complete power unit would be lifted to the high mountings by helicopter, an innovation incidently which is recently being used in California wind farms to achieve 'economies of scale' in installation.

In June, 1980, the inventor estimated that a 40 foot diameter, 3-stage compound helical could be installed for $20,000., each, in multi-unit, high tower arrays. In this scenario, 75,000 units are mounted in an array covering eight to ten square miles and in a wind regime capable of producing an annual average output per hour of 15 kW-h for each unit. In this cost analysis, each 'power-unit' includes the windmill, frame, steering mechanism, alternator, electrical components, controls and a proportional share of the cable mounting, power house and real estate. The inventor estimates that such an array would produce as much energy as a 1,875 MW fossil or nuclear plant operating at a 60% capacity factor.

The following is an estimate of 'The Projected Cost of Electric Energy' made by the inventor in July, 1981:

Wind Engine Size and Type

- 48 foot diameter, 3-stage compound
- 36 foot diameter, 10-blade, helical

U.S. Patents "4,065,225" & "4,171,929"

General Assumptions

- Interest at .19%
- Operation and Maintenance at 4 mills per kwh produced
- Amortize over 30 year period (equal yearly payments against principal)
- Efficiency of generator and transmission at 80%

Case 1) - 48 foot diameter compound

Assumptions

- Complete installation cost of $30,000.00
- Maximum capacity of generator/alternator = 60 kw
- Average wind velocity at site (50 feet above ground) = 15mph

Projected annual output = 192,720 kwh (annual average of 22kwh/hr.)

Cost during first year of operation

Interest on $30,000.00 - - - -	$5,700.00
Payment on principal - - - - -	1,000.00
Operation and Maintenance - - - -	771.00
Total Cost - - -	$7,471.00

Cost of electrical energy during first year of operation = 3.88¢/kwh

Case 2) - 36 foot diameter, 10-blade, helical

Assumptions

- Complete installation cost of $36,000.00
- Maximum capacity of generator/alternator = 130 kw
- Average wind velocity at site (50 feet above ground) = 15mph

Projected annual output =96,360 kwh (annual average of 11kwh/hr.)

Cost during first year of operation

Interest on $36,000.00 - - - -	$6,840.00
Payment on Principal - - - - -	1,200.00
Operation and Maintenance - - -	385.00
Total cost	$8,425.00

Cost of electrical energy during first year of operation = 8.74¢/kwh

Case 3) Windmill of Case 2 installed in an area of average wind of 30 miles per hour.

Projected annual output = 525,600 kwh (annual ave. of 60 kwh/hr.)

Cost during first year of operation

Interest on $36,000.00 - - - - -	$6,840.00
Payment on principal - - - - - -	1,200.00
Operation and Maintenance - - - -	2,102.00
Total cost - - - -	$10,142.00

Cost of electrical energy during first year of operation = 1.93¢/kwh

Presently, in California wind farms where the industry leaders are at an annual production level of 1,000 units, the typical installed price is $100,000 to $150,000. for a turbine with a diameter of 10 - 15 meters (33 - 50 feet). The brokerage cost is 5 - 15% 'off the top' of this cost while the manufacturing cost is $40,000. to $50,000. In the manufacturing cost, the rotor accounts for $10,000. and the drive train for another $10,000.

SUMMARY

One of the most exciting opportunities seen for this technology is to supply from 30% to 50% of U.S. highway transportation energy needs. Initially the energy could be used to support alcohol production to improve octane and reduce oil consumption. Eventually, when hybrid gas-electric cars become popular, a windmill in a sufficiently windy place would be as 'valuable as an oil well' to its owner. Even today, in areas of sufficient wind, wind energy is cost competitive with oil in supplemental, fuel-saving applications. According to the pace in the rise of the cost of oil, more and more wind sites will become cost competitive with that fossil fuel for many additional applications.

Today's conventional markets are the electric utilities and remote power. Given such a large market potential to expand into, the inventor envisages a wind engine production industry that may eventually be as large as the present truck production industry in the U.S.A.

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